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ABSTRACT

This self-contained student manual on fundamentals of radio and television repair is designed to help trade and industrial students relate work experience on the job to information studied at school. Designed for individualized instruction under the supervision of a coordinator or instructor, the manual has 9 sections, each containing 2 to 10 assignments. Each assignment follows this format: objectives that tell what the student is to learn from the assignment, information, and exercises to help the learner master the objectives. The first assignment is about how to use the manual. Topics covered in the other assignments include occupational outlook for radio and television service technicians, safety, basic electrical terms and symbols, operation of volt-ohm-milliammeter (VOM), vacuum tubes and semiconductors, basic radio, and basic television. (YLB)

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Radio and Television Repairer

Fundamentals

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Student's Manual

By
Chuck Maul

U.S. DEPARTMENT OF EDUCATION
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Foreword

This publication is one of a series of self-contained instructional materials for trade and industrial students. Each student who uses this material can work at his or her own pace, learning those things that best fit her or his specific needs. The design of the material makes it possible to relate work experience on the job to information studied at school.

Although the material is individualized, it should be used under the supervision of a coordinator or instructor. For that reason, two basic publications are now offered—a student's manual and a coodinator's guide.

The *student's manual* is written for the person in training. It includes assignments, objectives that tell what the student is to learn from each assignment, and exercises to help the learner master the objectives.

The *coordinator's guide* for each manual has additional information to help the coordinator help the student. There are suggestions on how the student should use the manual and how the instructor can coordinate work experience and learning at school. Further information is given as needed on how to help students achieve related skills in mathematics, reading and communication, and principles of science. These pages are not included in every guide; they are tailor-made to fit the occupational situation. The coordinator's guide also contains (1) answers to both exercise questions and assignment test questions, (2) one set of assignment tests, and (3) work sheets. The coordinator can conveniently use these to match related instruction to job experience for each student.

Although both the manual and the guide are copyrighted, the coordinator should feel free to reproduce tests and work sheets. These have been placed in a separate section of the guide, where they are readily accessible for copying. If the coordinator prefers, copies of this section may be ordered for individual students from this Center.

Jack E. Robertson, Director
Center for Occupational Curriculum Development

A Special Note to the Student

The assignments in this manual are designed to help you learn. You will gain more from this material if you know how to work the assignments. For that reason, Assignment A-1, which is about how to use this manual, should be completed first.

Section

A

Introduction

A-1. How to Use This Student's Manual
A-2. Occupational Outlook for Radio and Television Service Technicians

A-1

How to Use This Student's Manual

Objectives: After completing this assignment, you should be able to—

1. tell the four steps in completing an assignment;
2. explain the purpose of carefully reading the assignment objectives before reading the information;
3. give the procedure for studying an assignment;
4. tell why the assignments in this manual have been placed in a particular order or sequence;
5. tell how assignment exercises can help you learn;
6. explain how repetition is used to help you learn; and
7. tell how your coordinator can use your assignment test to help you;

The material in this manual has been prepared in the form of short assignments. Each assignment is similar in form. For instance, each assignment begins with objectives and ends with exercise questions.

There are four steps to follow in completing each assignment. First, read the objectives. Second, read the information contained in the assignment. Third, answer the exercise questions. Fourth, answer the assignment test. Follow this same procedure for all the assignments in the manual.

Assignment Objectives

The objectives for each assignment point out what you should have learned when you have completed the assignment. Each objective is also a statement of what you should be able to do after studying the assignment. When you can answer the exercise questions correctly, you have successfully met the objectives. A close study of the objectives will help you to be able to answer questions in the assignment exercise and test.

Assignment Information

The information for an assignment should be read twice. After you have done this, you should carefully study the information. It is also important to study every illustration that goes along with the information as you read it each time.

If you have never studied basic electricity and electronics or had any experience working in this field, you should start at the beginning of this manual and work through every assignment in the proper order. The assignments in this manual are in a sequence that should be followed to gain the most in learning. The study of radio and television can be compared to the process of multiplication and division. In mathematics, you need to know how to multiply before you can learn how to divide. In this same way, you must know something about basic electricity before you can understand much about electronics.

Exercise and Assignment Test

The exercise questions at the end of each assignment, like the objectives, are based on the most important information. By writing out the answers to these questions, you will be repeating the information you have just read. This will help you learn it. Many assignments have illustrations (figures). These illustrations will cover the same information that you have read. This is another form of repetition that will help you learn the information and be able to answer correctly the exercise questions and the assignment tests.

You should write the answers to the exercise questions on another sheet of paper because your coordinator may want to use this manual again. As soon as you have answered the questions, you should tell your coordinator so he or she can help you check your answers. This will let you know at once if you have learned the information. You might need to go back and read some of the information again. If not, your coordinator will let you take the assignment test. The assignment test will help you to learn the information still better. You will be able to complete each assignment at your own rate. Your coordinator will be able to tell when you are ready to go on to the next assignment by how well you answer the assignment test.

Exercise

1. What are the four steps in completing an assignment?
2. What is the purpose of carefully reading the objectives before reading the information?
3. What is the procedure for studying an assignment?
4. Why have the assignments been placed in a particular order or sequence?
5. How can assignment exercises help you learn?
6. How is repetition used to help you learn?
7. How can your coordinator use your assignment test to help you?

A-2

Occupational Outlook for Radio and Television Service Technicians

Objectives: After completing this assignment, you should be able to—

1. name four electronic products, other than radios and television sets, repaired by television and radio service technicians;
2. tell what service technicians look for in making routine checks to find the cause of equipment breakdown;
3. tell how many radio and television service technicians were employed in 1978, and whom they worked for;
4. tell the kind of training, and some of the subjects, that might provide a good background for entering the field;
5. tell what is needed to be fully qualified as a service technician;
6. tell how manufacturers, employers, and trade associations provide important training;
7. name four abilities related to sight and hearing that are important to service technicians;
8. tell how service technicians can advance to other positions; and
9. name events that will increase the employment of service technicians;

Many questions come to mind when you are concerned with choosing an occupation. How interesting is the occupation? What are the qualifications? How much education is required? You should have an interest in the occupation and some confidence in your own ability to be successful in that field before going into it.

Radio and television servicing is an occupation that is within the ability of any average high school student to learn. However, you must be interested in the study of electricity and electronics to do well in this field.

You should know other things about an occupation before you decide on it. What are the advantages and disadvantages of the job? What is done on the job? Where is the work done? What are the earnings you can expect? These questions are answered by publications from the U.S. Department of Labor. A special help to those seeking occupational information is the *Occupational Outlook Handbook*, issued by the Bureau of Labor Statistics. The most recent edition of this handbook can be found in your own school library or through your school counselors. The following information is taken from the 1980–81 edition, Bulletin 2075.

Nature of the Work

Television and radio service technicians repair a great number of electronic products—especially television sets and radios. They also repair stereo components, tape recorders, intercoms, and public address systems. Service technicians may specialize in one kind of equipment, such as television sets or car radios.

Equipment may break down because of faulty tubes or transistors, poor connections, or other problems. Service technicians check and evaluate each possible cause of trouble. They start by checking for the most common cause—tube or module failure. In other routine checks, they look for loose or broken connections and for parts that are charred or burned. Unusual odors coming from the equipment often signify overheated parts.

When routine checks do not locate the trouble, technicians use test equipment, such as voltmeters, oscilloscopes, and signal generators, to check suspected circuits. For example, they may measure voltages or waveforms in a television set until an unusual or irregular measurement shows the faulty part. Once they find the cause of the trouble, they replace and make adjustments, such as focusing and converging the picture or correcting color balance.

On customer service calls, technicians carry tubes, modules, and other parts that can be easily replaced in the customer's home. Radios, portable television sets, and other small equipment are usually repaired in service shops. When complex test equipment must be used to locate the trouble in large television sets, they also are repaired in shops.

Service technicians use screwdrivers, pliers, wire cutters, soldering irons, and other hand tools. They refer to wiring diagrams and service manuals that show connections and provide information on how to locate problems and make repairs.

Places of Employment

About 131,000 people worked as radio and television service technicians in 1978. About one-fourth of them were self-employed. This is a larger proportion than in most skilled trades. Two-thirds of all service technicians, either self-employed or working for others, worked in shops and stores that sold or serviced television sets, radios, and other electronic products.

Television and radio service technicians work in almost every city. Geographically, employment is distributed in much the same way as the nation's population.

Training, Other Qualifications, and Advancements

Training and experience in electronics are required in order to become a skilled television and radio service technician. Certain technical, vocational, or high school training might provide a good background for entering the field. Some of the subjects that could be helpful are electronics, mathematics, schematic reading, and physics. The military services offer training and work experience that would be useful in civilian electronics work. Correspondence school courses can also be helpful.

To become a fully qualified service technician, a person needs two to four years of on-the-job experience and up to two years of technical training in electronics. People who have no previous technical training may be hired as helpers or apprentices if they show aptitude for the work. A hobby in electronics, such as being a "ham" radio operator, can be helpful in getting a job as an apprentice or helper. The apprenticeship training lasts about four years and sometimes includes home study. The apprentice must work with a fully qualified service technician who is responsible for his or her work.

Manufacturers, employers, and trade associations provide an important part of the service technician's training. They keep service technicians informed on the latest servicing methods for new models or products. By attending training seminars, and by studying technical magazines and manufacturers' service manuals, technicians keep up with technical developments. Those who work as technicians for large companies are more familiar with their own company's brand and work mostly on those products.

Television and radio service technicians need to know how electronic components and circuits work. The ability to handle small parts and tools, good eye-hand coordination, normal hearing, and good eyesight and color vision are also needed by the technician. The ability to work with people is also helpful.

Service technicians who work in large repair shops may be promoted to supervisor or service manager. Technicians may open their own sales and services shops when they have the necessary funds. Some technicians obtain jobs as electronic "troubleshooters" or technicians in manufacturing industries or government agencies.

Those who want to advance to positions such as electronics technician can improve their opportunities by taking trade school, correspondence, or technical institute courses. Such courses may include automatic controls, electronic engineering, television engineering, and mathematics. Business administration courses, particularly accounting and consumer relations, should be taken by those who plan to open up their own business.

Radio and television technicians are required to be licensed in many states. To obtain a license, applicants must pass an examination that tests their knowledge of electronic circuits and components and their skill in the use of testing equipment.

Employment Outlook

Through the mid-1980s, the number of television and radio service technicians employed will grow faster than the average for all occupations. There will be many openings each year to replace experienced technicians who retire, die, or change occupations.

The growing number of radios, television sets, phonographs, tape recorders, and other home entertainment products should increase the employment of service technicians, even though the new solid state products have a low failure rate. Improvement in technology will not change the situation. As the population and personal incomes rise, there will be a growing need for service technicians. Most households have a television set. The number of households with more than one set is expected to increase significantly because of the growing demand for color and portable sets. Increased use of such electronic products as closed-circuit television, two-way radios, calculators, home appliances, and various medical electronic devices is also expected. Closed-circuit television is being used increasingly to monitor production processes in manufacturing plants and to bring educational programs into classrooms.

Changes in economic conditions have little effect on the television and radio repair business. For this reason, people who enter this occupation should have steady work.

Earnings and Working Conditions

In 1978, the earnings of television and radio service technicians, according to limited information, ranged from $4.00 to $8.75 an hour. Differences in skill level, type of employer, and geographic location account for the variations in wages.

Television and radio service technicians employed in local service shops or dealer service departments usually work 40 to 48 hours a week.

Service on television, radio, and other home entertainment products is done in shops and homes. The working conditions are usually pleasant. Some physical strain is involved in lifting and carrying equipment. Hazards include electrical shock and the risk of falling from roofs while installing or repairing antennas.

Some service technicians are members of labor unions. Most of these belong to the International Brotherhood of Electrical Workers.

Sources of Additional Information

More information about jobs in this field can be obtained from the following sources:

- Local shops and stores that service television sets, radios, and other electronic equipment
- A local of the International Brotherhood of Electrical Workers
- Technical and vocational schools that offer television and radio repair courses or electronics
- Local office of the state employment service

These sources can provide specific information regarding apprenticeship and other programs that provide training.

Information of a more general nature about television and radio repair work can be obtained from:

- National Association of Television and Electronic Servicers of America
  5908 South Troy Street
  Chicago, Illinois 60629
- Electronics Industries Association
  2001 Eye Street, N.W.
  Washington, D.C. 20006

It is important for a person in the electronic servicing business to keep up with the latest developments and opportunities to learn new information. This should be done in any occupation.

Exercise

1. What are four electronic products, other than radios and television sets, repaired by television and radio service technicians?
2. In making routine checks to find the cause of equipment breakdown, what do service technicians look for?
3. How many radio and television service technicians were employed in 1978, and whom did they work for?
4. What are some useful subjects and appropriate training that might provide a good background for entering this field?
5. What is needed to be fully qualified as a service technician?
6. How do manufacturers, employers, and trade associations provide important training?
7. What are four abilities related to sight and hearing that are important to service technicians?
8. How can service technicians advance to other positions?
9. What events will tend to increase the employment of service technicians?

Section
B
Safety

B-1. General Job Safety
B-2. Electrical and Electronic Safety

Objectives: After completing this assignment, you should be able to—

1. name precautions to take when handling a picture tube;
2. name precautions to observe while installing or repairing roof antennas; and
3. list safety rules for using common hand tools and power tools on the job.

B-1

General Job Safety

When you arrive at a customer's home to pick up or deliver electronic equipment, you should be concerned with safety. Remember that *carelessness* has been the cause of more injuries than any other factor. Whether you are in a customer's home or in the repair shop, you should **practice safety at all times**.

Clothing

The kind of clothing you wear on the job has a lot to do with safety. You should not wear loose-fitting clothes or jewelry that could catch on anything. Never wear shoes that could easily slip in the repair shop or while making customer service calls. Avoid metal jewelry, such as rings and watches, that might come in contact with an energized electrical circuit.

Lifting and Carrying Electronic Equipment

You will often have to lift heavy television sets on the job. When lifting such loads, your legs should be slightly bent so that the weight of the load is lifted with your legs and not your back. When the load is too heavy for one person, always have another person help you.

Special care in lifting and carrying television picture tubes is necessary. A picture tube can *implode* when dropped. This means it will *burst inward*, which is more hazardous than an explosion, with regard to flying glass. To be prepared for such a mishap, you should **wear a protective face shield when handling picture tubes**.

When replacing picture tubes, leave the new one in the protective box as long as possible. You should remove the old one from the set and have everything ready before taking the new tube from its container. Place the old picture tube face down until you can put it into the special protective container. The old picture tube should be discharged by a clip lead wire to the chassis ground before removing the tube anode wire. Always grasp the picture tube at the widest area possible. Never carry it by the narrow part of the neck where it might break. A scratch or blow on the bell of the tube could cause an implosion.

Special Precautions at the Customer's Home

Routine checks on electronic equipment are often made in the home. Never try to troubleshoot electronic equipment that you are not familiar with. When your employer gives you the necessary instruction and you have all of the available manufacturer's service data, you are ready to make these routine checks. You should observe the same safety precautions working on electronic equipment in the customer's home as you would in the repair shop.

Some of the most important safety precautions are covered in Assignment B-2. It would be impossible to list everything you need to know about electrical and electronic safety at this time. As long as you work in radio and television repair, new types of electrical and electronic devices will be added. This means that new safety precautions will also be added. New uses for old electrical or electronic circuits will also make it necessary to learn new safety precautions. Some special circuit safety precautions will be mentioned later when you are learning about those particular electronic circuits. **In this occupation, safety is a continuous process**.

During customer service calls, you may need to advise the customer about the safe operation of electronic equipment in the home. For example, you should check the condition of power line cords used on electronic equipment and replace any frayed wires. Also, check the condition of the power line plug that fits into the wall receptacle. Repair any loose wire at either metal terminal of the plug, or replace the plug.

Look for signs of burning at the wall plug or where the power line cord enters the equipment. An odor coming from the electronic equipment indicates something has overheated and burned. A selenium rectifier, which will be discussed later, causes special trouble when it burns out. The fumes from this are extremely poisonous. If this happens, turn off the equipment immediately, and open the windows for ventilation. If you notice water leakage around electronic equipment, wipe up the water before turning on the electrical power.

Antenna Installation Safety

Radio and television antennas may be mounted in different ways at the customer's home. Sometimes, the antenna mast is mounted on a long pole or tower supported from the ground. Most of the time, it is mounted on the roof.

It is often necessary to use a ladder during the installation or repair of antennas. Falls from ladders cause a great many injuries every year. To prevent such accidents, remember this:

1. Repair or replace loose or broken steps and defective bracing.
2. You may need to have someone help support the ladder.
3. Set the ladder on dry, level ground.
4. Don't try to make outside antenna repairs or installations when the weather has caused unsafe, slippery conditions.

When working on roof-mounted antennas, watch out for loose gravel and loose or broken shingles that you might slip on. On older homes, antenna brackets may be screwed into rotten wood. When you are repairing an antenna, grasp it and test how securely it is mounted before you begin to work on it. If the structure sways when you touch it, take it down and reinstall it. Always have someone else support the antenna mast while you are taking it down.

General Safety in the Repair Shop

Many of the safety precautions you have learned about regarding customer service calls also apply to the repair shop. The proper maintenance of tools and equipment is important to the safety of employees in the shop.

Hand Tools

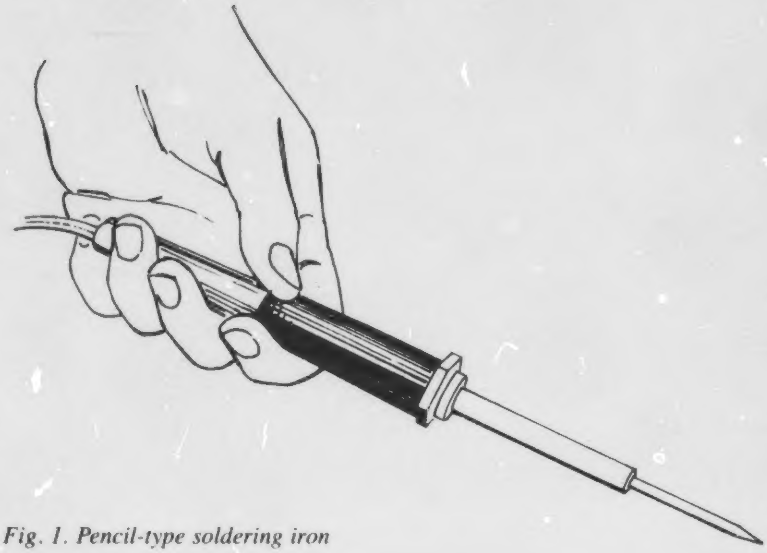


Fig. 1. Pencil-type soldering iron

The handles of all electrical tools should be made of nonconductive material. When handles break, they should be replaced or discarded. When handles break on screwdrivers, files, and similar tools, the pointed tang that fits into the handle is left uncovered and can cause puncture wounds and cuts.

Always select the correct size of screwdriver to fit the size of the screw slot. Screws with chewed-up heads have sharp metal burrs that can cause bad cuts.

When using a fuse puller, you should be sure it is the right type and size for the fuse being pulled. Find the cause of the overloaded circuit that caused the fuse to burn out, so repairs can be made.

Soldering irons can always be a source of burns. Treat every soldering iron as though it had just been used and was still hot. The iron holder should always be kept in the open, so heat will not accumulate and cause a fire. Always rest the iron on its rack or some other suitable metal surface. To prevent needless burns, always clamp or hold with pliers any small components to be soldered. Never dispose of excess solder by shaking the iron. A piece of flying solder could hit someone, causing a burn. Or the hot solder could land on equipment, causing a short circuit. Be sure to unplug the soldering iron as soon as you finish the job. Even if you just take a short break and will only be gone for a short time, *unplug the iron* before you leave it. Figure 1 shows a common pencil-type soldering iron that is used in radio and television repair.

Power Tools

Do not attempt to operate any power tools in the repair shop until you have learned the necessary safety precautions. You should also have the permission of your employer before using them.

It is a good idea to have a trial run for power tools whenever possible. For example, when drilling a hole in a metal chassis, turn the drill on and off quickly just before beginning to drill. By doing this, you will be able to tell if the drill is operating properly. You will also notice if the drill bit has been placed improperly in the chuck.

Exercise

1. What precautions should be taken when handling a picture tube?
2. What type of clothing should not be worn on the job?
3. What are four safety precautions that should be observed while installing or repairing roof antennas?
4. List ten safety rules regarding radio and television repair hand tools.
5. What are three general safety rules to observe about power tools?

B-2

Electrical and Electronic Safety

Objectives: After completing this assignment, you should be able to—

1. tell what should be done if a shock victim is discovered near electrical or electronic equipment;
2. tell three things you can do while working on energized electrical equipment to prevent shocks;
3. explain the principle of electrical grounding;
4. tell what safety precautions should be taken while working on electronic equipment that is not plugged into the electrical power line; and
5. tell what kinds of fire extinguishers to use on particular types of fires.

Electrical Shock

As long as you work on electrical circuits, you will always need to remain alert. You should know what to do if you come upon a person who has received a bad electrical shock.

Shock prevention is as important as knowing what to do if you discover a shock victim. Never touch any sort of electrical appliance that you suspect is defective until you are certain that the power is turned off.

Do the right thing when you come upon a victim of shock—or do nothing at all. If it appears that the victim was shocked by electrical equipment, disconnect the equipment at the wall outlet without touching the equipment. When you are certain there is no electrical contact with the victim, you may do what you can to help. If the person is not breathing, get help from an Emergency Medical Services unit, if possible. Artificial respiration should be administered as soon as possible. You should learn this procedure of cardiopulmonary resuscitation (CPR) so that you will be prepared for any such emergency.

Energized Circuits

At times the radio and television repairer will need to operate the electronic equipment while troubleshooting it. There are special AC power cords available for this purpose. They are called *cheater cords*. The service repairer must remove the back of the television set to be able to work on the various circuit components. A special interlock switch is installed in the back of the set. When the back is removed, the interlock switch disconnects the AC power line from the television set as a safety precaution. A cheater cord is designed to bypass the interlock connection. It connects directly from the electrical power wall outlet to the television. The service repairer should use a cheater cord to test equipment in operation for as short a period of time as possible. The particular circuit fault may also be overloading circuit components, causing more damage to these components.

Troubleshooting inside the chassis of electronic equipment can be dangerous when the power is turned on. You should **always keep one hand in your pocket when reaching inside a live set**. If you should receive a shock, the current would not pass through your heart as it would if both hands touched an energized circuit. On some televisions and radios, one side of the AC power line is connected to the metal chassis of the set. These are called "hot chassis sets." A special safety device called an *isolation transformer* should be used on all hot chassis sets to remove the shock hazard.

Make certain that you put the television cabinet back together *correctly*. Never substitute metal knobs or allow external cabinet screws to touch the chassis. If any metallic connection is made between the chassis and a metal part of the cabinet, the customer could receive a shock while operating the set. A common test used to detect such an unsafe condition is the resistance-to-chassis ground measurement. Such a test should be made after any repairs or adjustments have been made and before the set is returned to the customer.

The test instrument you will later learn to use to make the *antenna cold test* is called an ohmmeter. Resistance is measured in units called ohms. The antenna cold test is a resistance measurement made between the chassis ground and the antenna terminal screws. It is done with the AC plug removed from the 120-volt wall outlets. A jumper wire is placed across the two metal prongs of the set's AC plug. The switch is turned on. One lead wire of an ohmmeter is connected to the jumpered AC plug. The other lead of the ohmmeter is touched to each antenna terminal screw or coaxial connector if it is used. If the resistance measured is less than 1 megohm (1 million ohms) or greater than 5.2 megohms, an unsafe condition exists and should be corrected. The same test should be repeated also with the AC switch turned off.

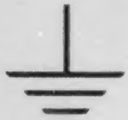


Fig. 1. True ground

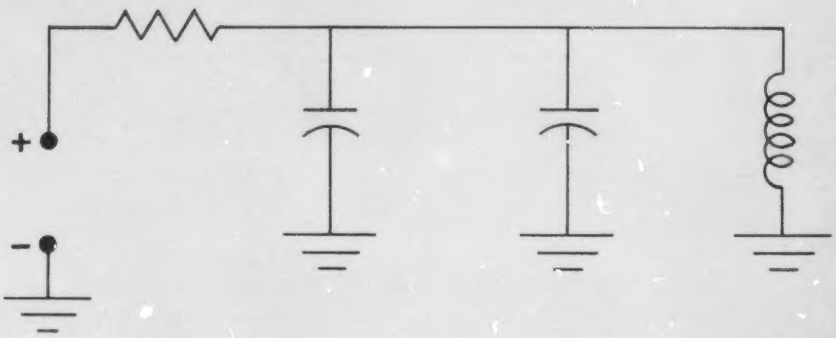


Fig. 2. Common ground

Proper Circuit Grounding

One of the most important electrical principles is that of electrical grounding. A *grounding wire* is a non-current-carrying wire. It is often called the *third wire* and is included in the same wiring harness or cable with the current-carrying wires. This grounding wire should be connected to parts of the equipment that do not ordinarily carry electrical current. For example, the third wire on portable power tools and electrical appliances is connected at one end to the outer metal frame. The other end should be connected to the third prong of the three-pronged safety wall plug.

If the building has been wired correctly, the third wire from the wall outlet is connected to the *true earth ground*. A short circuit can be caused by a current-carrying wire accidentally touching the metal frame. If this should happen, the dangerous current would drain off through the third wire to the earth ground. This would prevent a fatal shock to a person who might come in contact with the metal frame. The symbol for a true ground is shown in figure 1. This same symbol is also used for what is called a *common ground*. This is used in complicated electronic schematics to substitute for a wire running between a great many circuit components. An example of this is shown in figure 2. By the use of the common ground, electrical safety is promoted because there is less chance for error in reading the more simplified drawings.

Nonenergized Circuits

Even though electronic equipment is not plugged into the AC power line, you could receive a shock under certain conditions. An electrical circuit component called a *capacitor* has the ability to store an electrical charge. You will learn to identify capacitors and to discharge them before you probe around in that area. They can be discharged by touching the two wire leads to them with a metal screwdriver. When you do this, **be sure you are holding an insulated handle** so that the current cannot discharge through the screwdriver into your body. Use the same technique to discharge the high voltage remaining on the metal anode of a picture tube. Place the screwdriver blade on the anode of the picture tube, while touching the screwdriver tip to the chassis ground. This will discharge the current.

The high-voltage rectifier section of television sets should be approached with caution. The cathode-ray tube should be discharged, to avoid coming in contact with the high voltage being delivered by the rectifier. A *rectifier* is an electronic device that changes alternating current into direct current. This is necessary in all radios and televisions because almost all of the electronic components in them must operate on direct current.

Fire Prevention and Safety

Keeping the work area clean is an important part of fire prevention in any repair shop. Dust that collects inside the cabinets of radios and television sets can easily ignite and lead to a serious fire. Any sort of grease or oil deposits might be ignited by an electrical arc.

If a fire should occur on a power cable running through electronic equipment, the cable should be cut with an insulated cable cutter. A wooden-handled ax might also be used if a cable cutter is not available.

If a fire starts in electrical or electronic equipment, first turn off the electrical power, and then call for help. You should try to extinguish the fire with a *carbon dioxide* fire extinguisher. When directed at the base of the flame, this type of fire extinguisher will smother the fire. No other type of fire extinguisher should be used on electrical fires.

A *water* fire extinguisher should be used on porous materials such as cloth, paper, and wood. For such common types of fires, water is always a very convenient and effective extinguisher.

Special electrical cleaners, gasoline, oil, and kerosene are also a common cause of fires in repair shops. A *foam* fire extinguisher should be used for fires involving these substances. *Never use water.*

Exercise

1. What should be done when a shock victim is discovered near electrical or electronic equipment?
2. How can a radio or television set be operated with the back re-

moved and the interlock switch disconnected?
3. What are "hot chassis sets," and what safety device should be used on them?
4. What is a grounding wire, and how does it prevent electrical shocks?
5. What is a common ground?
6. What is the purpose of a capacitor in electrical circuits?
7. How should you discharge a capacitor?
8. How can you eliminate the high voltage remaining on a television picture tube after the power has been turned off?
9. What safety precautions should be taken when working in the vicinity of the high-voltage rectifier?
10. Why is a rectifier needed in radios and television sets?
11. What is the first thing to do if a fire starts in electrical or electronic equipment?
12. What kind of fire extinguisher should be used on an electrical fire?
13. What kind of fire extinguisher should be used on an oil fire?
14. On what kind of fire is it safe to use water?

Section

C

Basic Electrical Terms and Symbols

C-1. Electron Theory
C-2. Basic Electrical Circuits and Ohm's Law Relationships
C-3. Magnetism and Electromagnetism
C-4. Inductance
C-5. Capacitance

C-1

Electron Theory

Objectives: After completing this assignment, you should be able to—

1. name the electrical particles in an atom;
2. define *ionization*;
3. explain how the modern electron theory differs from Ben Franklin's conventional flow theory;
4. tell how the fundamental law of charges is related to electron flow through a conductor;
5. compare electron flow to water flowing through a pipe with regard to voltage, current, and resistance; and
6. explain Ohm's law and its three formulas.

Radio and television servicing and repair is based on the radio and television technician's understanding of how electricity works. The discovery of the electron microscope has greatly increased our knowledge of how electricity works.

Electricity in motion is the movement of electrons. All of the elements contain *electrons* (negatively charged particles) in their atomic structure. Figure 1 shows how electrons orbit around a central nucleus that is composed of *protons* (positively charged particles of electricity). There is the same number of these positive (+) protons as there are negative (−) electrons in the atom. This causes the atom to be balanced. The lighter electrons can sometimes be shaken loose from an atom and moved on to another atom. This is what happens in a metal conductor. **Electricity is the movement of electrons from atom to atom through a conductor**. Figure 2 shows how an element having ten electrons has one electron shaken loose. This electron travels to the nearest atom where it repels an electron belonging to the new atom, which in turn moves on to the next atom. These moving electrons are called *free electrons*. Good conductors are metallic substances that have some of the electrons so loosely bound to the nucleus that they are free to move from atom to atom. A very small force can cause such electrons to shake loose from the atom and become free electrons. Substances having few free electrons are poor conductors.

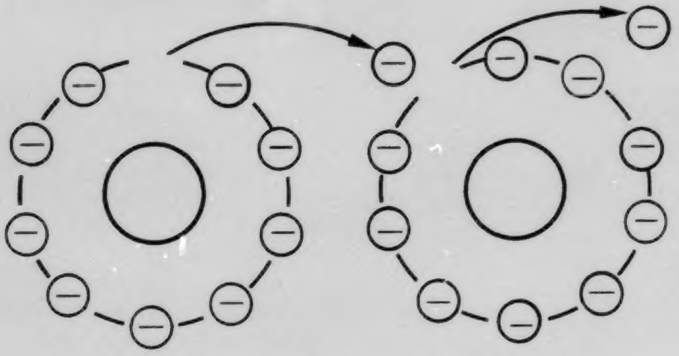


Fig. 2. Movement of electrons between atoms

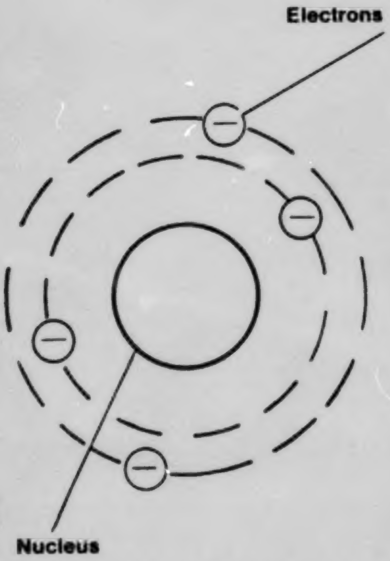


Fig. 1. The electron theory

Ionization

An atom that has lost or gained one or more electrons is called *ionized*. If it has lost electrons, it has become a **positive ion**. If it has gained electrons, it has become a **negative ion**. This process is called *ionization*.

Insulators, Conductors, and Semiconductors

To control the movement of electrons, it is necessary to cover the substance with some material that will restrict their movement. This material is called an *insulator*. Some of the best insulators used in radio and television sets are mica, rubber, glass, dry air, asbestos, and bakelite.

Silver is the best *conductor*, but it is seldom used in electrical wiring because it is so expensive. Copper and aluminum are the second and third best conductors of electricity. Zinc, brass, and iron are also used as conductors in radios and television sets.

In between the conductor and the insulator, regarding free electrons, is the *semiconductor*. Germanium and silicon are commonly used as semiconductors in radios and television sets. Under some conditions a semiconductor may act as a conductor, and under other conditions as an insulator.

Direction of Electron Flow

Most American automobiles are designed to be negative ground. This means that the negative (−) terminal of the auto battery is connected to the metal chassis of the automobile. The positive (+) terminal of the battery is connected to the starter motor. This is an example of the old "conventional flow" of electrons as Ben Franklin viewed it. It is assumed that the electrons will flow out of the positive terminal of the battery to the starter motor and other electrical circuits. The return path would be through the automobile chassis to the negative terminal of the battery.

According to the conventional flow theory, the direction of electron flow is from positive to negative. We know today that *electron flow is from negative to positive*. It is only a relative thing as to whether the output terminal of an auto battery is stamped positive or negative. Most of industry has accepted the electron theory, and in most applications it has replaced the old conventional flow theory.

Fundamental Law of Charges

This law of charged bodies has been frequently demonstrated in science classes using two light pith balls suspended near each other on threads. A hard rubber rod is rubbed, giving it a static negative charge. When this rod is placed in contact with one of the balls, that ball has a greater negative charge than the other ball. The two balls are then attracted to each other and will stick together. This proves that **unlike charges attract**. If the same charge is placed on both balls, they swing away from each other on their threads. This proves that **like charges repel**.

Voltage: The Force That Moves Electrons through a Conductor

Now you can put together all that you have learned about electricity. Imagine that eight billiard balls are lined up, as in figure 3, inside a hollow tube. If you think of the *voltage* as a stick striking ball number one, you can see that a chain reaction takes place. The force of each ball reacts on the next one until the number eight ball pops out the other end of the tube. This is exactly what happens to electrons. An imbalance caused at one end of a wire conductor by a *voltage source* causes the free electrons in the conductor to line up. Since these negative electrons are the same charge, they repel each other. This chain reaction takes place at the rate of 186,000 miles per second.

Another term that has been used to mean voltage is *electromotive force* (emf). From this, the letter *E* has become the most widely accepted symbol for voltage. Occasionally, you may see *V* used to represent voltage. Voltage can be measured in an electrical circuit with a *voltmeter*. The unit of measure is called the *volt*.

Current: The Movement of Electrons

The French scientist Charles A. de Coulomb did a great deal of experimentation with charged particles of electricity. The unit of measure to represent a quantity of electrons was named after him. The unit of *one coulomb* has been taken to represent 6,242,800,000,000,000,000 electrons. It is quite evident from this large number that some shortened method of notation is needed when dealing with such large numbers. The decimal point

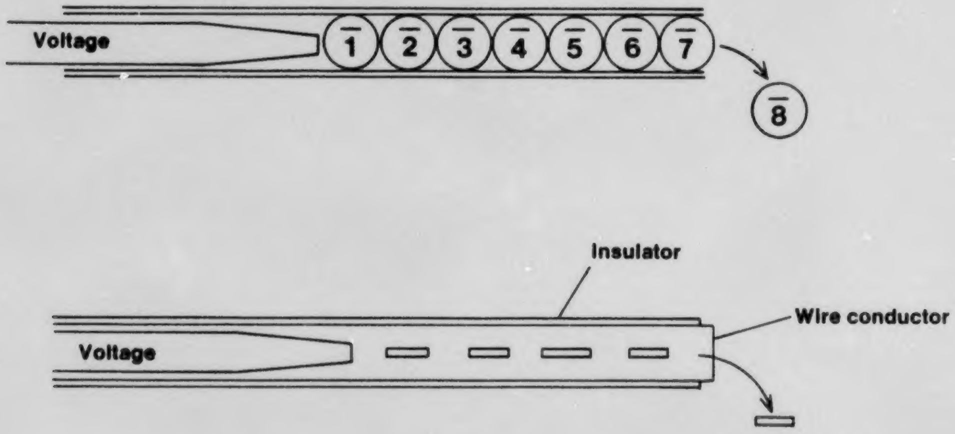


Fig. 3. Voltage is the force that causes electrons to move through a conductor.

can be moved eighteen places to the left, and the number becomes 6.24 × 10^{18}. Each decimal place represents a power of ten. The small number 6.24 could be used in multiplication or division problems as long as you remember to move the decimal point to the right eighteen places in the answer. The exponent *18* (to the power of ten) tells you how many times ten is used as a factor. For example 10^3 is ten used three times, or 10 × 10 × 10. Therefore, $10^3 = 1{,}000$.

Current is the term used to mean the flow of electrons through a conductor. The symbol used for current is the letter *I*. Current flow can be measured with an *ammeter*. The unit of measure for electric current is the *ampere*. One ampere is equal to one coulomb of electrons flowing past a given point in one second.

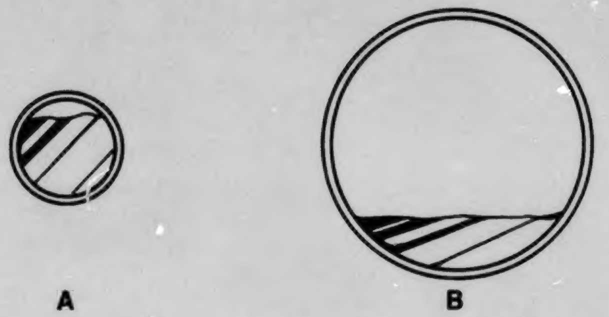


Fig. 4. Water flows more easily, or with less resistance, through a larger pipe.

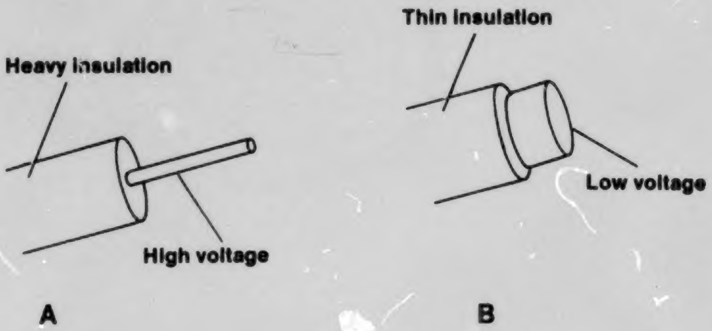


Figure 5

Resistance in Electrical Circuits

Water being pumped through pipes can be compared to current flowing through wire conductors. The more friction that is present while water moves through a pipe, the more it will slow down or retard the water flow. You can see in figure 4 that if the same amount of water flows through both pipes there will be less friction in pipe B. The water will flow more easily, or with less resistance, through pipe B. In figure 5, the same amount of current flows through both wires. The thin wire at *A* must have a higher voltage to force the current through it. The resistance is much higher since the friction is greater than at *B* for the heavy wire.

The unit of measure for electrical resistance is the *ohm*. The resistance can be measured in ohms using an *ohmmeter*. The letter *R* and the Greek letter Ω (omega) are symbols used for resistance. The ohm was named after the German physicist Georg Simon Ohm.

Ohm's Law

One of the most basic laws used by radio and television service technicians is *Ohm's law*. The easiest way to remember it is to think of a pie cut in three parts, as in figure 6. You cover up the letter you want to find. The top letter E is considered to be above a division sign. The bottom two symbols are considered to have a multiplication sign between them. Thus, $E = I \times R$, $I = E/R$, and $R = E/I$ are the three formulas derived from Ohm's law. To have a good understanding of the relationship of voltage, current, and resistance, remember the following statement. **It takes one volt to force one ampere of current through one ohm of resistance.**

Power

The amount of power used in an electrical circuit is stated in *watts*. You can use a pie chart (it really spells PIE) to find the power (P) in watts. To find the value of one unknown, we must know the value of the other two quantities. When the current (I) and voltage (E) are known, then:

$$P = I \times E$$

Two other formulas to find the power involve the use of the square of a number, or a number multiplied times itself. When the resistance (R) and current (I) are known, then:

$$P = I^2R$$

When the voltage (E) and resistance (R) are known, then:

$$P = \frac{E^2}{R}$$

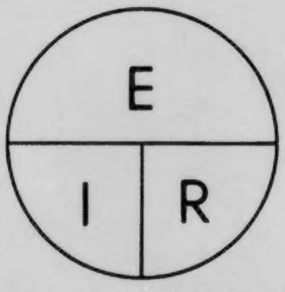


Fig. 6. Ohm's law relationship

One watt of power is used when one ampere of current is moved through an electrical circuit by the force of one volt.

In Assignment C-2, you will apply what you have learned to solve problems involving typical electrical circuits found in radio and television sets.

Exercise

1. What are the negatively charged particles in an atom called?
2. What are the positively charged particles called?
3. How is *electricity* defined in the assignment?
4. What are moving electrons called?
5. What is ionization?
6. What is an insulator?
7. What is the difference between the electron theory and Franklin's conventional flow theory?
8. State the *law of charges*.
9. How does the law of charges help explain the way electrons flow through a conductor?
10. With regard to voltage, current, and resistance, describe how electron flow can be compared to water flowing through a pipe.
11. What is Ohm's law?
12. What are the three formulas derived from Ohm's law?

Objectives: After completing this assignment, you should be able to—

1. multiply and divide with powers of ten;
2. identify resistors as a basic circuit component, and determine the resistance in ohms of a resistor by using the color code for resistors;
3. use Ohm's law to solve typical series, parallel, and series-parallel circuit problems;
4. explain the difference between direct current and alternating current; and
5. tell how each type of current flows in electrical circuits regarding the time period.

C-2

Basic Electrical Circuits and Ohm's Law Relationships

Powers of Ten

There are times when radio and television service technicians must work with extremely large numbers, as well as extremely small numbers, in solving problems involving electrical and electronic circuits. Knowing how to use the powers of ten is a necessity. Table 1 shows some of the most often used powers of ten.

For the whole numbers above the dotted line, the decimal point has been moved to the left to convert to a power of ten. You must remember to convert back to the original number of decimal places by counting to the right. It is just the opposite for the negative numbers below the dotted line. To change the number to a power of ten, move the decimal point to the right. To convert back to its original decimal location, count to the left. For example:

$.0000385 = 3.85 \times 10^{-5}$

$734{,}000. = 73.4 \times 10^{4}$

Multiplication with Powers of Ten

To multiply powers of ten, the powers of ten are exponents, so they are *added* together.

Example 1:

$.000003 \times .003$

$.000003 = 3 \times 10^{-6}$ and
$.003 = 3 \times 10^{-3}$

$= 3 \times 10^{-6} \times 3 \times 10^{-3}$

$= 9 \times 10^{-9}$

Example 2:

$21{,}000 \times 7{,}000$

$21{,}000 = 2.1 \times 10^{4}$ and
$7{,}000 = 7 \times 10^{3}$

then

$21{,}000 \times 7{,}000 = 2.1 \times 10^{4} \times 7 \times 10^{3}$

$= 2.1 \times 7 \times 10^{7}$

$= 14.7 \times 10^{7}$ or $147{,}000{,}000$

Division with Powers of Ten

To divide powers of ten, the law of exponents in division must be followed. The denominator below the division line is moved to above the line and the

Table 1

	The Number	The Power of Ten
	1,000,000	= 10^6 or 1×10^6 (ten to the plus 6)
	100,000	= 10^5 or 1×10^5 (ten to the plus 5)
	10,000	= 10^4 or 1×10^4 (ten to the plus 4)
	1,000	= 10^3 or 1×10^3 (ten to the plus 3)
	100	= 10^2 or 1×10^2 (ten to the plus 2)
	10	= 10^1 or 1×10^1 (ten to the plus 1)
POSITIVE	1	= 10^0 or 1
NEGATIVE	.1	= 10^{-1} or 1×10^{-1} (ten to the minus 1)
	.01	= 10^{-2} or 1×10^{-2} (ten to the minus 2)
	.001	= 10^{-3} or 1×10^{-3} (ten to the minus 3)
	.0001	= 10^{-4} or 1×10^{-4} (ten to the minus 4)
	.00001	= 10^{-5} or 1×10^{-5} (ten to the minus 5)
	.000001	= 10^{-6} or 1×10^{-6} (ten to the minus 6)

sign changed. That is, you *subtract* the lower exponent from the upper exponent.

Example 1:

$$\frac{10^7}{10^4} = 10^{7-4} = 10^3$$

Example 2:

$$\frac{63{,}000}{.0007} = \frac{63 \times 10^3}{7 \times 10^{-4}} = \frac{63}{7} \times 10^{3+4}$$

$$= 9 \times 10^7 \text{ or } 90{,}000{,}000$$

Combined Multiplication and Division with Powers of Ten

Multiply and divide alternately until the problem is solved.

Example:

$$\frac{.00052 \times 72{,}000 \times 2{,}400}{130{,}000 \times .0000016}$$

Convert the numbers to numbers between 1 and 10 times their power of ten.

$$\frac{5.2 \times 10^{-4} \times 7.2 \times 10^4 \times 2.4 \times 10^3}{1.3 \times 10^5 \times 1.6 \times 10^{-6}}$$

$$= \frac{5.2 \times 7.2 \times 2.4 \times 10^3}{1.3 \times 1.6 \times 10^{-1}}$$

Next, divide and multiply alternately. Thus, you divide 5.2 by 1.3 to get 4. Then multiply the 4 by 7.2 to get 28.8. The 28.8 is divided by 1.6 giving a quotient of 18. This quotient of 18 is multiplied by 2.4 resulting in the product of 43.2. Including the remaining factor of 10^4 you should arrive at the answer of 43.2×10^4 or 432,000.

Resistance Color Code

A color code is used to specify the resistance in ohms and the tolerance rating of a resistor. Resistors are manufactured in various sizes, wattage ratings, and accuracy tolerances.

Bands of color around the body of the resistor are used to give the resistance and the tolerance of the resistor. The first color band on the left is the first digit, as shown in figure 1. The second color band is the second digit, and the third color band is the multiplier. When a fourth color band is used, it specifies the tolerance rating of the resistor. A *gold fourth band* means that the resistor should be accurate ± 5%. For example, for a 100-ohm (Ω) resistor, the resistance can be +5%, or 105 ohms. It might also be under 100 ohms by 5%, or as low as 95Ω. A *silver fourth band* means a tolerance rating of 10%. When there is no fourth band, the tolerance rating is 20%.

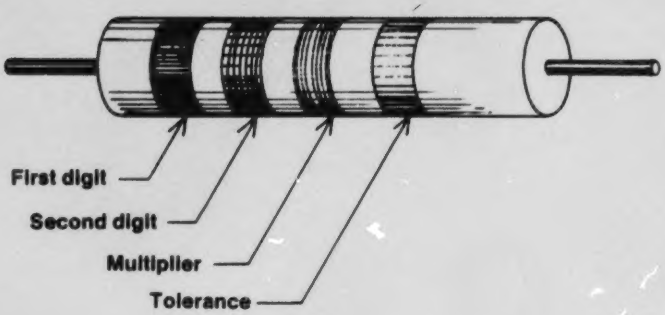


Fig. 1. Carbon resistor color code

Table 2 gives the resistor color code, and the values of each color.

Series Circuits

You should learn to use the various electronic symbols. It is a good idea to have a separate sheet of paper to draw these symbols as you learn them. You can begin by drawing your own copy of figure 2.

To find the current in figure 2, use the formula I = E/R.

$$I = \frac{6}{20} = 0.3 \text{ ampere}$$

So, 0.3 ampere of current runs through the 20-ohm resistor.

There are several basic laws relating to series circuits. The first law is that **at each resistance in a series circuit, there are values of voltages that will add up to the same value as the source voltage**. For example, in figure 3 the voltage source of 100 volts will be divided between R_1, R_2, and R_3. If there is a voltage drop of 50 volts at R_1 and 25 volts at R_2, there must be 25 volts at R_3 to add up to 100 volts.

The second law states that **the same amount of current flows through each resistance of a series circuit**. In figure 4, the total current (I_T) is 0.3 amp. The same value of current is found to pass through each resistor. Using Ohm's law, find the voltage drop

Table 2
Resistor Color Code

Color	1st Digit	2nd Digit	Multiplier	Tolerance
Black	0	0	10^0	—
Brown	1	1	10^1	—
Red	2	2	10^2	—
Orange	3	3	10^3	—
Yellow	4	4	10^4	—
Green	5	5	10^5	—
Blue	6	6	10^6	—
Violet	7	7	10^7	—
Gray	8	8	10^8	—
White	9	9	10^9	—
Gold	—	—	10^{-1}	5%
Silver	—	—	10^{-2}	10%
No Color	—	—	—	20%

at R_4 when $R_4 = 10$ ohms. You should use the formula $E = I \times R$. The current of 0.3 amp × 10 ohms = 3 volts for the value of E_4.

Basic Direct Current Circuits and Ohm's Law Relationships

The most widely used equation in the electronics servicing occupations is Ohm's law. It has special applications for each of the different types of electrical circuits.

The three forms of Ohm's law are:

$$\text{Current} = \frac{\text{voltage}}{\text{resistance}} \text{ or } I = \frac{E}{R}$$

$$\text{Voltage} = \text{current} \times \text{resistance, or } E = IR$$

$$\text{Resistance} = \frac{\text{voltage}}{\text{current}} \text{ or } R = \frac{E}{I}$$

The third law states that **all of the resistances in a series circuit must add up to equal the value of the total resistance of the circuit**. In figure 5, when the total resistance (R_T) equals 800 ohms, R_1 and R_2 add up to the value of 600 ohms. Subtracting this 600 ohms from the total resistance of 800 ohms leaves 200 ohms. So R_3 must be equal to 200 ohms, because $R_T = R_1 + R_2 + R_3$ in a series circuit.

Parallel Circuits

An easy way to remember the first two fundamental rules regarding voltage and current for parallel circuits is that they are reversed from the two rules you have just learned regarding series circuits. The rule for voltage in a parallel circuit is that the total voltage (E_T) passes through every resistance in the circuit. So the **voltage at each resistance is the same value as the total voltage**. For this reason, tubes and transistors found in radios and television sets are usually wired in parallel. However, the radio or television signal wave is interrupted if there is a failure at any stage in the equipment regardless of whether series or parallel circuits are used.

The second rule for parallel circuits is that **the total current (I_T) is equal to the total of all of the current values found at the resistances (or**

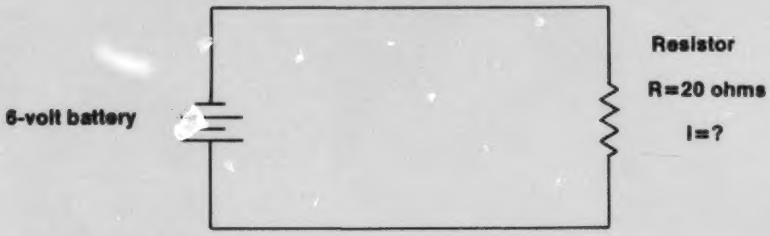


Fig. 2. Series circuit

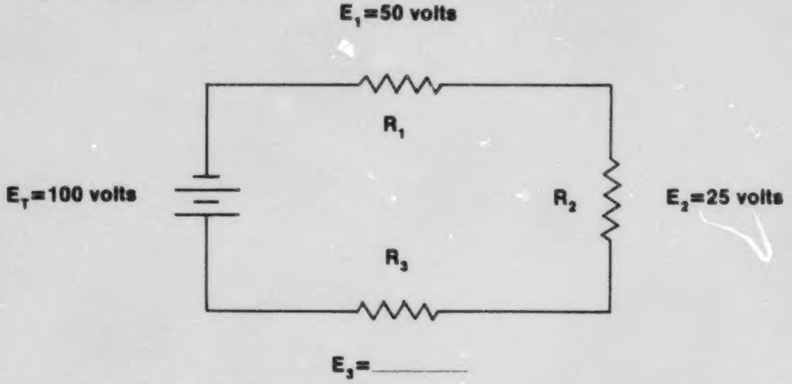


Fig. 3. In a series circuit, the voltage source (100 volts) is equal to the sum of the voltages of the individual resistances.

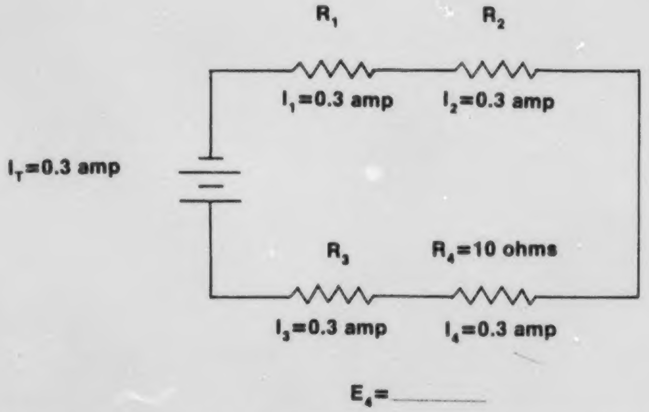


Fig. 4. In a series circuit, the same amount of current flows through each resistance.

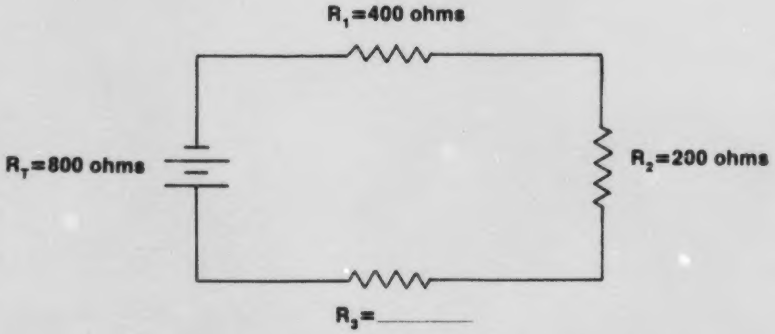


Fig. 5. In a series circuit, the total resistance is equal to the sum of the individual resistances.

loads) in the circuit. For the circuit in figure 6, when the total current is 3 amp, and $I_1 = 1$ amp and $I_2 = 1$ amp, the remaining current at I_3 must be 1 amp.

The third rule for parallel circuits regarding resistance is a little more complicated than the other rules. It involves the use of the reciprocal of a number. The reciprocal of a number is that number divided into the number one. The reciprocal of 100 would be 1/100, or 100 divided into 1. In a parallel circuit, **the reciprocal of the total resistance ($1/R_T$) is equal to the total of the reciprocals of the individual resistances in the circuit**. This is expressed by the formula

$$\frac{1}{R_T} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} + \ldots \frac{1}{R_n}$$

or

$$R_T = \cfrac{1}{\cfrac{1}{R_1} + \cfrac{1}{R_2} + \cfrac{1}{R_3} + \ldots \cfrac{1}{R_n}}$$

when "n" represents the number of resistors in a particular circuit. This formula can be used to compute the total resistance of two or more unequal parallel resistors. For example, in figure 7, the total resistance can be found for the values of 10 ohms at R_1, 20 ohms at R_2, and 30 ohms at R_3. The first step is to copy the formula you were just given for finding the total resistance in a parallel circuit. The next step is to substitute the resistance values for R_1, R_2, and R_3 into the formula. This gives:

$$R_T = \cfrac{1}{\cfrac{1}{10} + \cfrac{1}{20} + \cfrac{1}{30}}$$

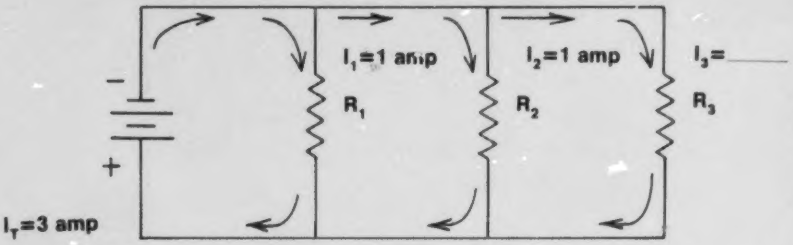


Fig. 6. In a parallel circuit, the total current is equal to the sum of the currents of the individual resistances.

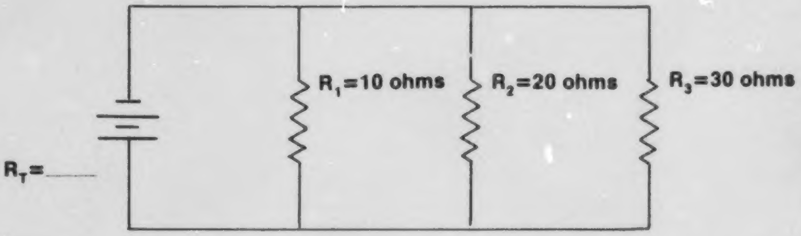


Fig. 7. In a parallel circuit, the reciprocal of the total resistance is equal to the total of the reciprocals of the individual resistances.

Find the least common denominator:

$$\frac{1}{10} = \frac{6}{60}$$

$$\frac{1}{20} = \frac{3}{60}$$

$$\frac{1}{30} = \frac{2}{60}$$

$$R_T = \cfrac{1}{\cfrac{6}{60} + \cfrac{3}{60} + \cfrac{2}{60}} = \cfrac{1}{\cfrac{11}{60}}$$

$$= 1 \times \frac{60}{11} = 5.45$$

From this you can see that the total resistance (R_T) is 5.45 ohms.

Series-Parallel Circuits

In actual electrical circuits found in radio and television sets, there are seldom "pure" series circuits or "pure" parallel circuits. They are usually combinations of series and parallel circuits.

Equivalent Series Circuits

To find unknown values of voltage, current, or resistance in series-parallel circuits, the parallel branch circuits are first reduced to equivalent series circuits. Then the entire circuit can be treated as a series circuit. For example, in figure 8A the series-parallel circuit has three resistors R_1, R_2, and R_3 in parallel. Resistor R_4 is in series with this parallel branch circuit.

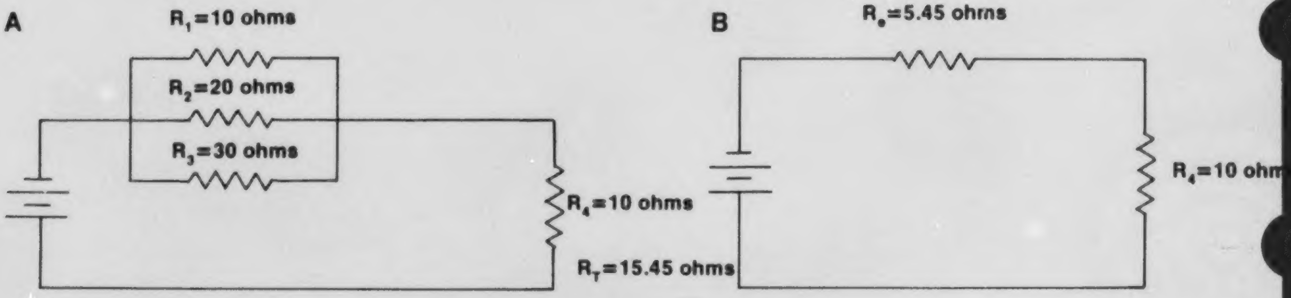
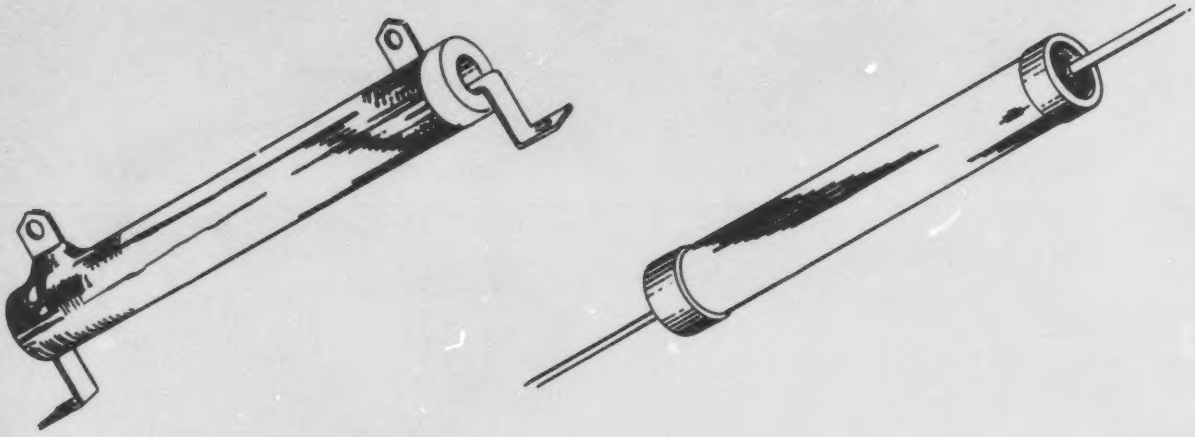


Fig. 8. Equivalent series circuits



Wirewound resistor **Power resistor**

Fig. 9. Two types of fixed resistors

The rules for parallel circuits regarding voltage, current, and resistance should be applied to the parallel branch. The parallel circuit can then be reduced to an equivalent series circuit. For example, the formula to find the total resistance of the parallel branch can be used as it was before.

Assume the values of the individual resistors are the same as they were for the sample problem just solved for parallel circuits: R_1 = 10 ohms, R_2 = 20 ohms, and R_3 = 30 ohms. You should review the sample problem again. In that problem, the total resistance (R_T) was 5.45 ohms. This is the same answer for the parallel branch series equivalent resistance in figure 8A. Now in figure 8B, this equivalent resistance (R_e) of 5.45 is added to the 10-ohm resistance (R_4) to give a total circuit resistance (R_T) of 15.45 ohms.

Basic Types of Resistors

Various types of resistors are used in radio and television sets to obtain the desired values of current and voltage. Their proper location in the set and the value in ohms are included in the manufacturer's service data that is available for every radio and television set. Practically any value of resistance can be placed in a circuit in a very small space.

The most common type of resistor is **the fixed resistor**. The resistance cannot be varied for the fixed type. For general applications, *carbon resistors* are used quite often. These resistors are the type that are color-coded with color bands. Two other types of fixed resistors are shown in figure 9. *Wirewound resistors* are used when high wattage is needed.

One of the applications of the *integrated circuits* (IC) so widely used today is the *resistor network* (fig. 10). In the integrated circuits, or "chips" as they are often called, entire electronic circuits containing several different components are formed in a very small space.

For some applications it is necessary to vary the values of current and voltage in a resistor by varying the resistance. The most common symbol for a **variable resistor** is the fixed resistor symbol with an arrow through it, or pointing to it ( ). Figure 11 shows a *potentiometer*. This variable resistor is used as a volume control in radio and television sets. A *rheostat* (fig. 12) is a similar device that is used in special electrical circuits to vary the

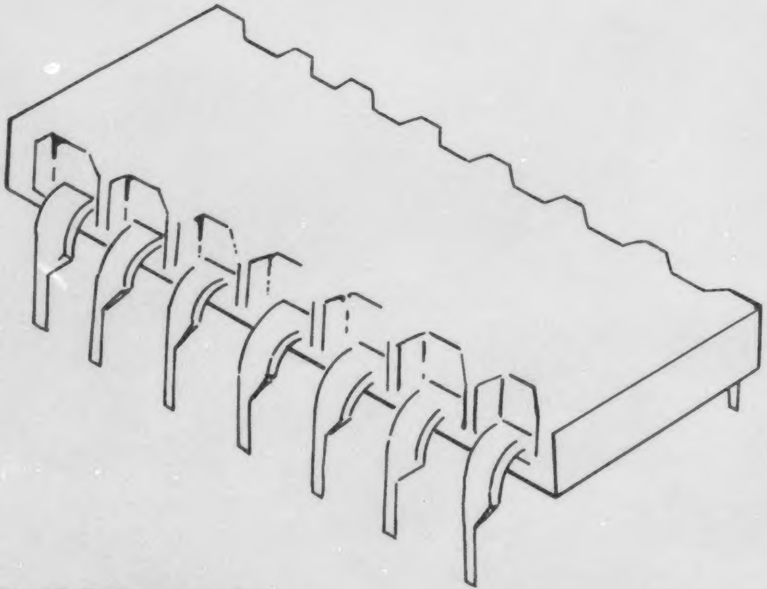


Fig. 10. Resistor networks

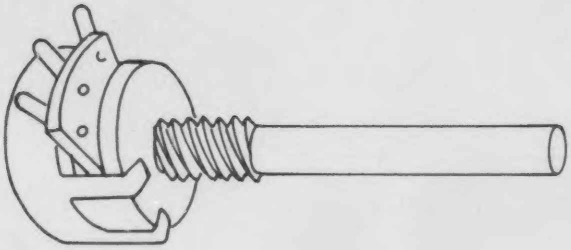


Fig. 11. Potentiometer

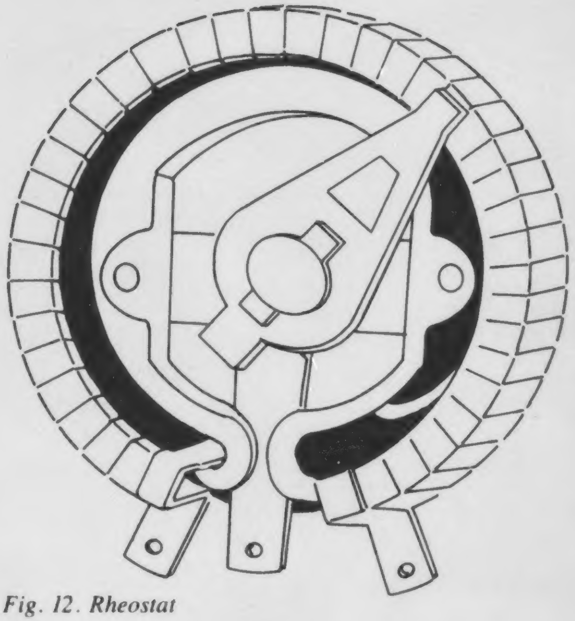


Fig. 12. Rheostat

resistance. One application for the rheostat is to vary the amount of current flowing through a lighting circuit, so as to adjust the lights to the desired brightness.

Alternating Current Circuits

Electrical circuits found in radio and television sets are made up of both *direct current* (DC) and *alternating current* (AC). Certain disadvantages of direct current have been overcome by the use of alternating current.

In alternating current circuits, the current does not flow constantly in one direction like direct current. Alternating current flows in one direction for a certain period of time, then reverses direction and flows in the opposite direction. The most well-known alternating current is the 60 cycles per second common household current. The 60 cycles per second, or 60 hertz, means that the current travels from the AC power plant to a house and back to the power plant *60 times in one second*. In other words, it changes direction 120 times in one second. Figure 13 shows this comparison graphically, in the AC sine wave curve.

As the AC voltage leaves the AC generator at zero potential, it gradually climbs on the positive half cycle until it reaches a positive 9 volts. This happens in the first quarter of the cycle. In the second quarter of a cycle, the voltage gradually decreases to zero and then changes (goes negative) direction to begin the third quarter of a cycle. It gradually increases in value until it reaches the maximum or peak value of 9 volts negative. In the last quarter of the cycle, the negative voltage gradually decreases, until it reaches zero potential and is ready to change direction again and start a new cycle.

The voltage source is the main difference between alternating current and direct current. A 9-volt battery like those used in transistor radios will deliver a constant DC voltage of 9 volts. This is illustrated in figure 14.

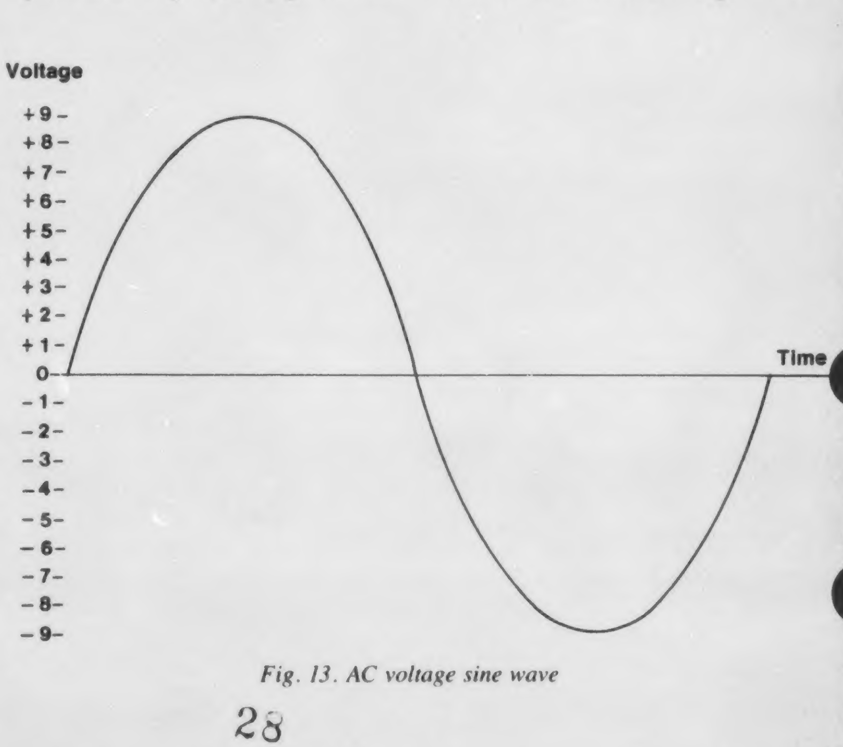


Fig. 13. AC voltage sine wave

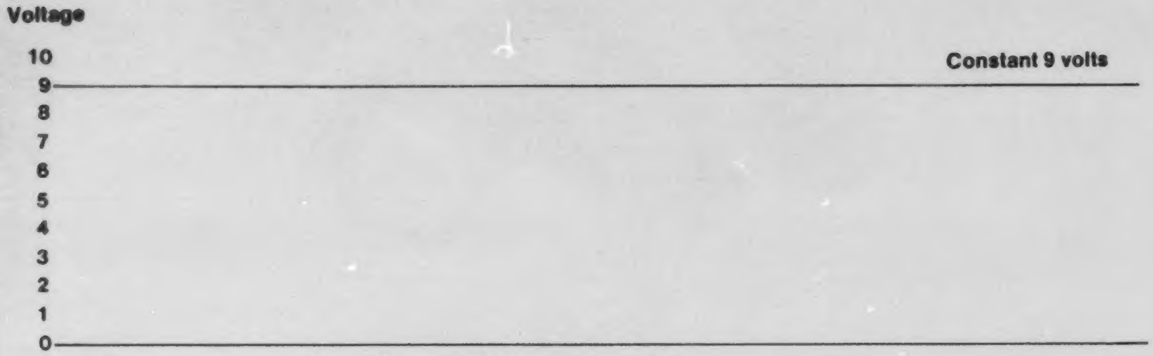
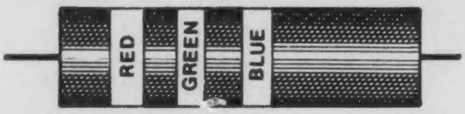


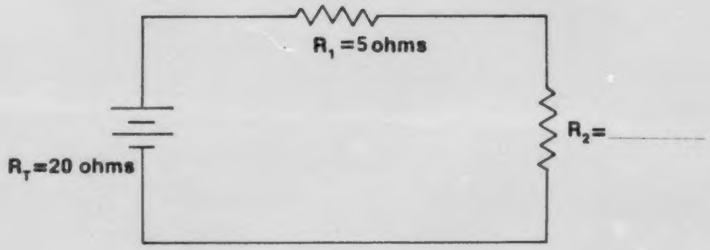
Fig. 14. DC voltage

Exercise

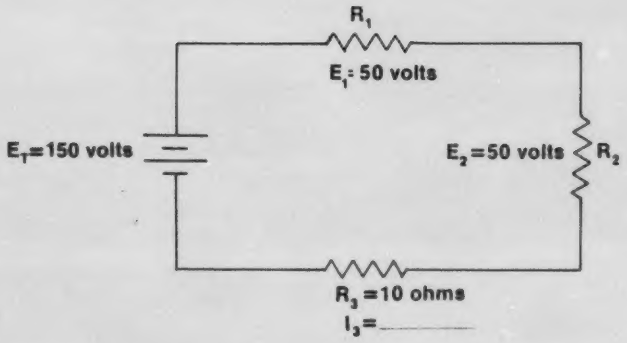
1. Multiply .000005 × .005 using the powers of ten. Show all your work when you convert to powers of ten.
2. Divide 72,000 by .00009 using the powers of ten. Show all your work, including the conversion to powers of ten.
3. What is the resistance of this resistor?


RED
GREEN
BLUE

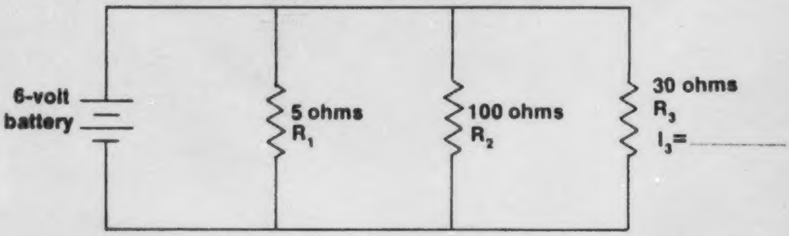
4. In the series circuit shown here, what is the value of R_2 in ohms?


R_1 =5 ohms
R_2=
R_T=20 ohms

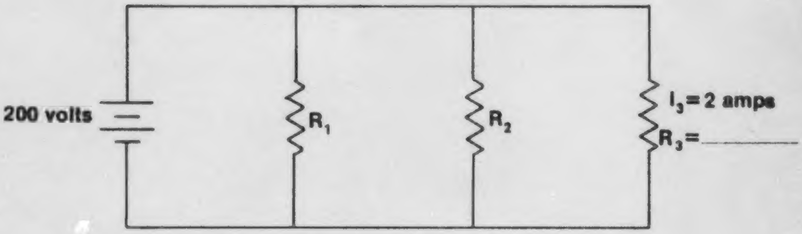
5. In this circuit, what is the value of the current (I_3) at R_3?


R_1
E_1= 50 volts
E_T=150 volts
E_2=50 volts
R_2
R_3 =10 ohms
I_3=

6. For this circuit, find the current (I_3) at R_3 when the voltage source is 6 volts.


6-volt battery
5 ohms
R_1
100 ohms
R_2
30 ohms
R_3
I_3=

7. In this circuit, what is the value of the resistance at R_3?


200 volts
R_1
R_2
I_3=2 amps
R_3=

8. What is the difference between direct current and alternating current?
9. Define the *period* of an alternating-current sine wave.

C-3

Magnetism and Electromagnetism

Objectives: After completing this assignment, you should be able to—

1. explain the laws of magnetic attraction and repulsion;
2. tell what purpose a magnetic screen serves;
3. define *electromagnetism*;
4. tell how Rowland's law can be compared to Ohm's law; and
5. tell how magnetic circuits are similar to electrical circuits.

Magnetism

Permanent magnets have been made from hardened steel or special alloys, and natural magnets have been found in several parts of the world. These magnets attract metals such as iron, steel, cobalt, and nickel. Permanent magnets are often used in electrical meters and instruments. They are also found in magnetos, loudspeakers, and telephone receivers. Figure 1 shows a magnetic speaker.

Temporary magnets retain a small amount of magnetism even after the magnetizing force has been removed. This is called **residual magnetism**. This type of magnetism is used to help increase voltage in special self-excited DC generators.

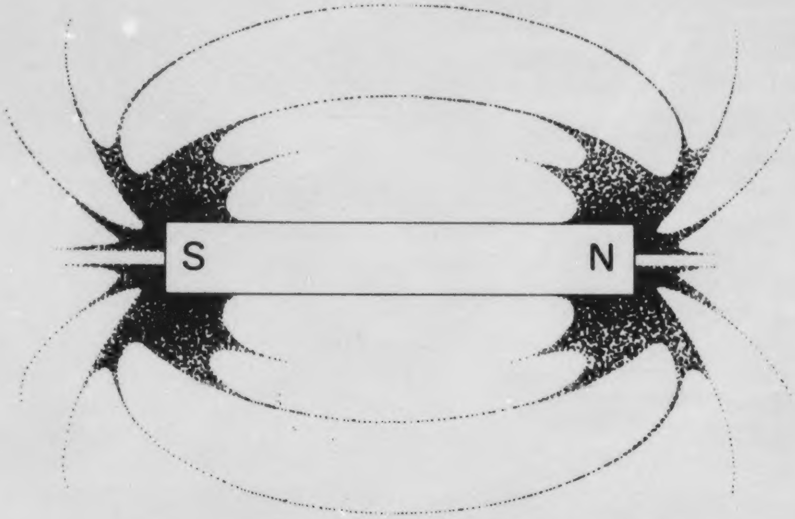


Fig. 2. Magnetic field

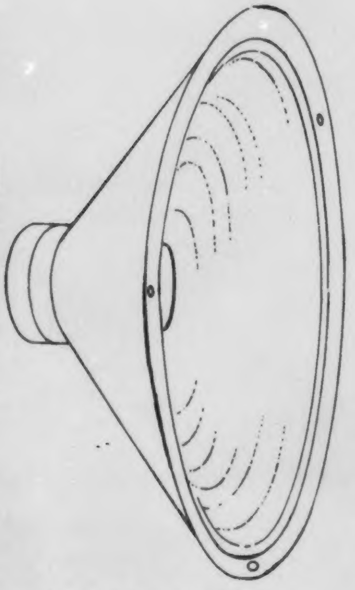


Fig. 1. Magnetic speaker

Magnetic Fields

You cannot actually see magnetic lines of force, but the effect of this field of force can be seen in figure 2. A thin sheet of paper or a glass plate is placed over a bar magnet. Iron filings are sprinkled over the outer surface. You can see that the filings arrange themselves in a definite manner between the north and south poles. The field tends to be symmetrical. It is also known that the *lines of force* come out of the north pole and enter the south pole. The complete magnetic field is called **magnetic flux**. In a magnetic circuit, the *flux* can be regarded in the same way as *current in electrical circuits*.

Laws of Magnetic Attraction and Repulsion

If two bar magnets are suspended near each other, the *like poles will repel* each other, and the *unlike poles will attract* each other. The north pole of one magnet and the south pole of the other magnet will end up facing each other because of this repulsion and attraction, as shown in figure 3.

There is another important law of magnetic attraction and repulsion. This law states that *the force of attraction or repulsion between two magnetic poles rapidly decreases as the poles are pulled away from each other*. There are definite mathematical relationships regarding this law that will be learned later on in your study of the field of radio and television.

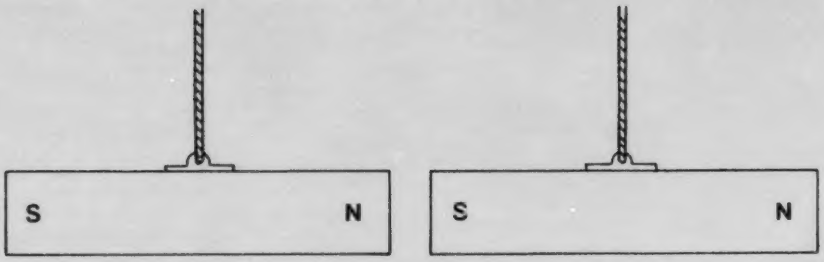


Fig. 3. Results of magnetic attraction and repulsion

The Magnetic Screen

Electrical instruments and meters, such as the volt-ohm-milliammeter (VOM), are extremely sensitive to the influence of stray magnetic fields. These magnetic fields cause errors in their readings. *Mu metal* is a magnetic insulator that has been used effectively in some instances to shield the meter. The flux will go through nonmagnetic materials such as wood, rubber, or glass. This is one great difference between a magnetic circuit and an electrical circuit. These same substances act as good insulators in electrical circuits.

To solve this problem of stray magnetic fields, a *magnetic screen* has been used. This is a soft iron case placed around the instrument. The flux will travel an even longer distance to reach the soft iron case than to reach the nearby air in the case. It will do this because the soft iron is a magnetic material and will more easily absorb the flux. The effect is to divert the flux away from areas in the instrument where it would do harm.

Electromagnetism

Electromagnetism is the magnetic field of force around a conductor caused by the movement of electric current through it. Any electric current moving through a conductor produces a magnetic field. In the case of a single conductor carrying current, the magnetic field will form into concentric circles as shown in figure 4.

When several loops or turns of wire are turned close together, as in figure 5, a magnetic force extends from one end of the coil to the other end. A polarity is established. One end becomes a north pole, and the other end a south pole.

Electromagnets

A coil of wire turned around an iron core is called an *electromagnet*. An electromagnet has a polarity and a magnetic field just like a coil. When alternating current is used in electromagnets, as in the operation of electric motors, the iron cores are heated and there is energy loss. When the current changes direction in rapid succession, the magnetism of an electromagnet also changes direction and this causes heat. The heating effect is mainly due to hysteresis and eddy currents.

Hysteresis is a kind of molecular friction, caused by the reversals of the magnetic fields at high speed. The higher the frequency, the greater the hysteresis loss in an electromagnet.

Eddy currents are currents circulating through the iron core. These currents are produced when the magnetic field changes in intensity. To reduce the heating effects (and power losses) due to eddy currents, the cores of electromagnets are often laminated. This means that the cores are made from bundles of soft iron wire or sheets that have been insulated from each other to block the eddy currents.

Magnetomotive Force

When a number of turns of wire are wound close together and continuously in the same direction around a core, a *coil* or *solenoid* has been formed. The combined magnetic field is the sum of those produced by the individual turns.

This magnetic force brought about by a coil or solenoid is called the *magnetomotive force* (*mmf*). It is directly proportional to the number of turns in the coil and the current flowing through it. The magnetomotive force is proportional to the product of the turns and the current. This unit is known as an *ampere-turn*. The *gilbert*, designated by the letter F, is also used as a unit to represent magnetomotive force.

Magnetic Circuits and Ohm's Law Equivalent

The path of the magnetic lines of force leaving the north pole, passing through the circuit, and returning to the south pole is called a *magnetic circuit*. It can be a series, parallel, or series-parallel circuit.

It was mentioned earlier that current flow in electrical circuits can be compared to the flux in magnetic circuits.

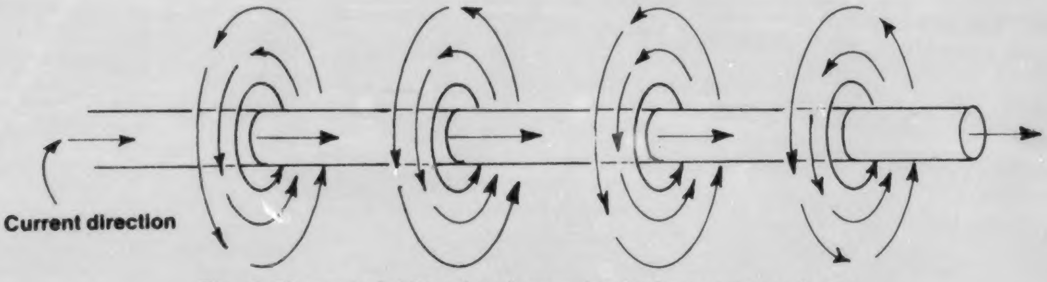


Fig. 4. Magnetic field produced around a single straight conductor

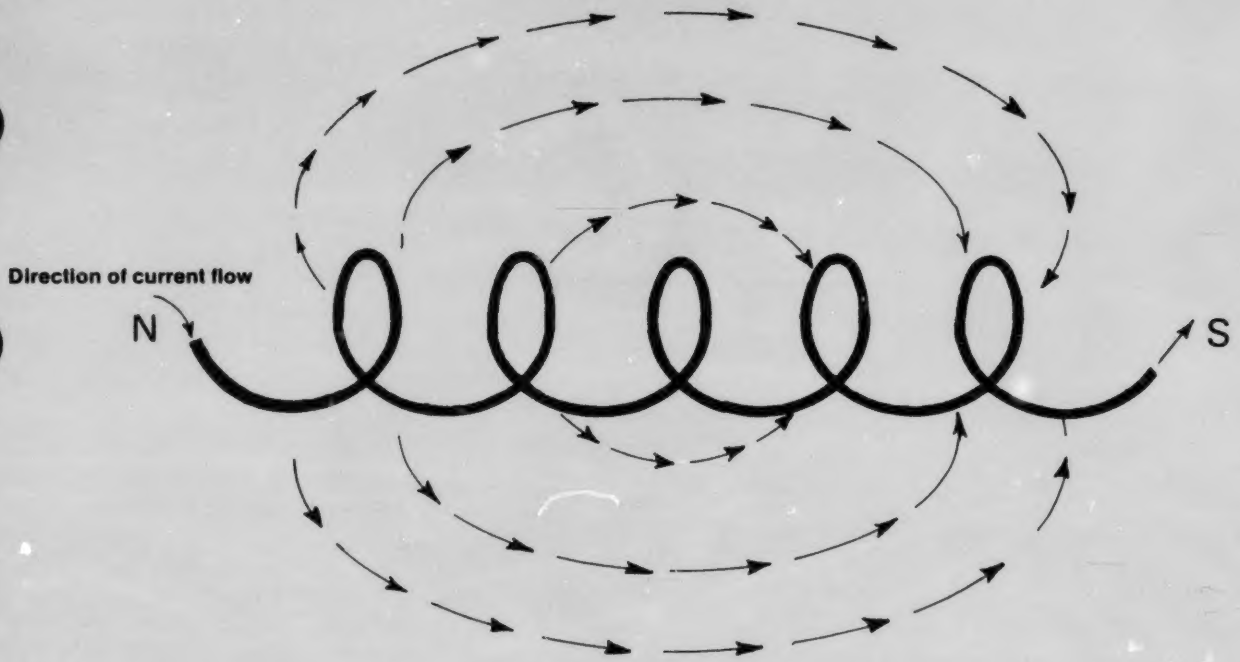


Fig. 5. The magnetic field surrounding a coil

You recall that Ohm's law for electric circuits can be expressed in the equation $I = E/R$.

There is a law for magnetic circuits that is quite similar to Ohm's law. It is called *Rowland's law*. In Rowland's law, the unit that corresponds to resistance is called *reluctance* (R). Flux (ϕ) is expressed in a unit called maxwells, and the magnetomotive force is in gilberts (F). Rowland's law is expressed in the following equation.

$$\phi = \frac{F}{R}$$

You can easily see the similarity to Ohm's law,

$$I = \frac{E}{R}$$

where comparisons can be made between flux (ϕ) and current (I). Similarities can also be seen between magnetomotive force (F) and voltage, as well as between reluctance (R, pronounced *rel*) and resistance.

To express the magnetomotive force as ampere-turns, this formula is used.

$$F = 1.257\ I\ N$$

In the formula, I represents current in amperes, and N the number of turns of wire in the circuit. The symbol F is the magnetomotive force in gilberts.

Another unit, designated as H, represents the intensity of magnetizing force per unit of length. It is sometimes given in gilberts per centimeter of length. The mathematical formula for this is

$$H = \frac{1.257\ I\ N}{l}$$

The length in centimeters is represented by l.

The reluctance (R) is the opposition of the magnetic circuit to the passage of magnetic flux. The unit of reluctance, the rel (R), is the opposition or reluctance offered by a 1 centimeter cube of air. Expressed as a formula, this is:

$$R = \frac{l}{\mu(A)}$$

The length in centimeters is l. *A* is the cross-sectional area in square centimeters, and the Greek letter mu (μ) represents the permeability. The permeability of air is considered to be 1. Permeability is a measure of how well a substance can conduct magnetic lines of force as compared to air.

Exercise

1. How does magnetic attraction and repulsion influence magnetic circuits?
2. What is a magnetic screen?
3. What is electromagnetism?
4. Describe the properties of magnetic fields.
5. How is Rowland's law similar to Ohm's law?
6. How are magnetic circuits similar to electrical circuits?
7. What is the unit in electrical circuits that reluctance is similar to?

C-4

Inductance

Objectives: After completing this assignment, you should be able to—

1. explain the principle of electromagnetic induction;
2. define *mutual induction*;
3. define *inductance*;
4. give the formula for finding the time constant in an inductive circuit; and
5. tell how the resistance and the inductive reactance in an inductive circuit can be used to find the impedance.

Electromagnetic Induction

The most common method of obtaining electricity in bulk is through the use of an AC generator. This is possible because of the principle of electromagnetic induction.

This assignment will be concerned with magnetism as it is affected by electric current flow, and electric current as it is affected by magnetism. A magnetic field can be made to create a voltage, thus causing current to flow in a conductor, as in figure 1. The symbol Ⓐ is used in electronics to represent an *ammeter*. A very small amount of current would actually be detected in the circuit shown. There must be motion of the wire before there is current. The magnets create flux. The flux travels from out of the north pole into the south pole. Considering the motion of the wire to be as shown, use your left hand and point your thumb in the direction the wire moves and your index finger in the direction of the flux. Your second finger should now be pointing at you, and this is the direction that the induced current will flow. This is called the *left-hand rule*.

In figure 2, current is induced in the loop of wire by the *motion of the magnetic field* through the wire. It produces the same results. Current will flow in the wire and be detected by the ammeter.

Increasing the Turns in a Coil Increases Voltage

The value of the voltage created by a single wire cutting a magnetic field is quite small unless the magnetic field is very strong. That same wire might be wound into a 300-loop coil. The coil

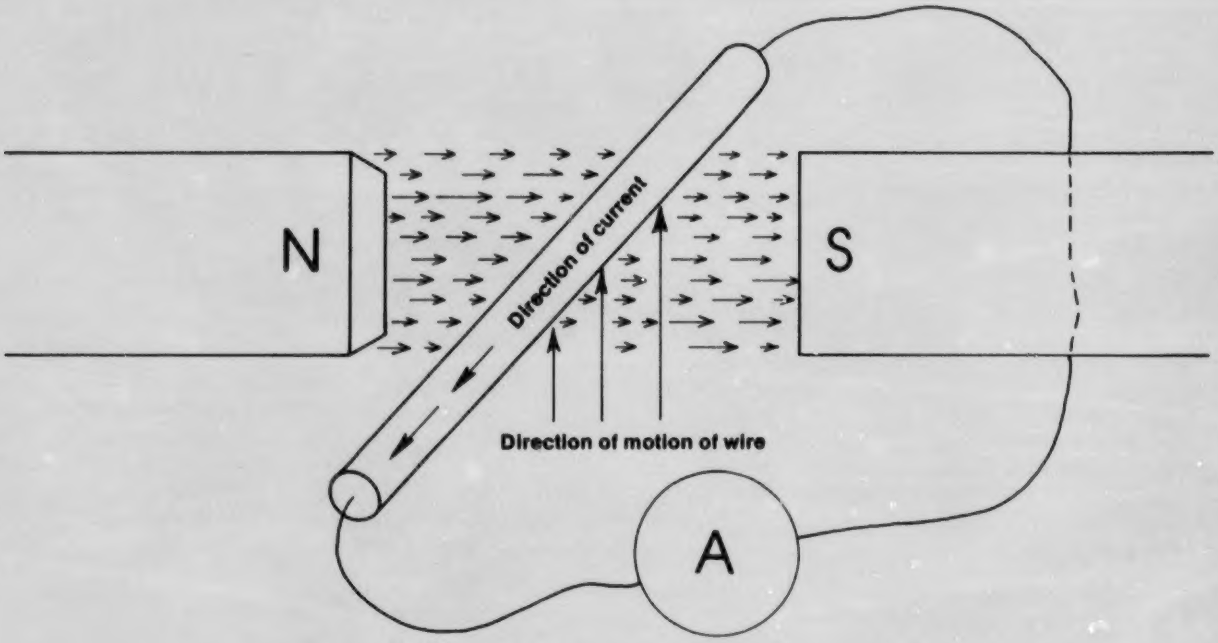


Fig. 1. Electromagnetic induction

would then produce the same effect as if the original single length of wire had moved through a field 300 times as strong as the original field. The speed of the movement is also a factor affecting the value of the induced emf. A much greater emf is induced when the motion is rapid than when it is slow.

It should be noted that there is never a transfer of current from one circuit to the other. The primary winding in a *power transformer* like those used in radios and televisions (see fig. 3) is not connected to the secondary winding. It is *coupled magnetically*. It would not be correct to say that the current of the secondary is induced from the primary circuit. Only emf (voltage) can be induced. The current that flows in the secondary is a result of the induced voltage. Of course, there must first be a voltage before current can be created. This was learned previously from the study of the electron theory.

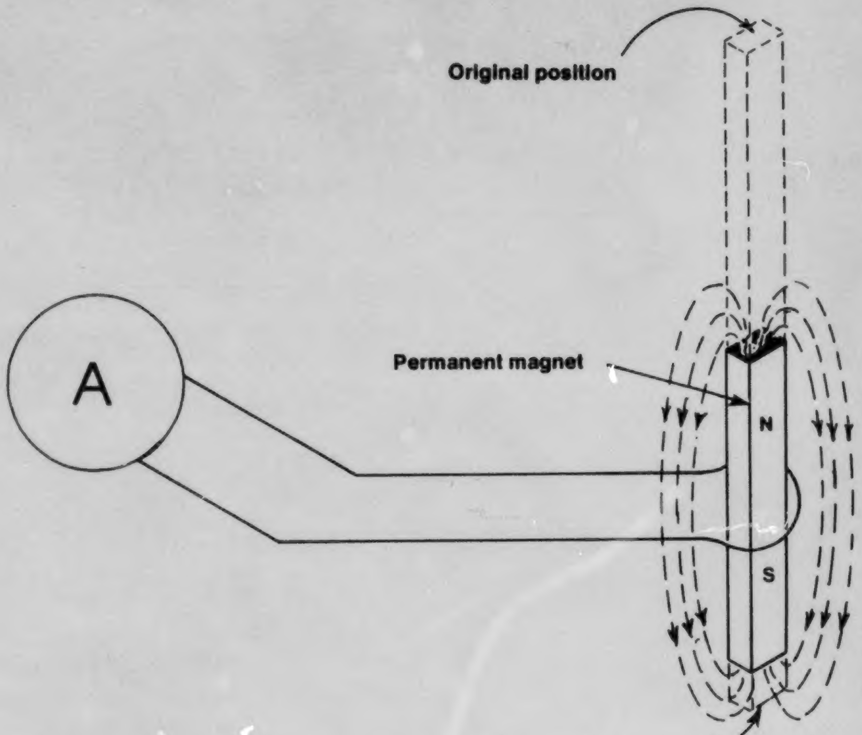


Fig. 2. Electromagnetic induction

Mutual Induction

The production of a voltage in a circuit when the circuit has been cut by a *variable flux* (magnetic field) from a nearby circuit is called *mutual induction*. In the direct current circuit of figure 4, the flux is varied by the opening and closing of the switch S_1. If S_1 is closed (turned on), the current flowing through *A* will cause a magnetic field to expand enough to cut the other wire *B*. A voltage with an opposing polarity will be induced in *B* during the time the flux is building up. If S_1 is opened (turned off), no current flows with the battery disconnected, but another momentary voltage will be induced in *B*. This is caused by the collapsing magnetic field. The polarity of the voltage again changes in *A* to be opposite to the polarity of the voltage induced by the previous expansion of the flux. Any change in the current of the primary circuit causes either an expansion

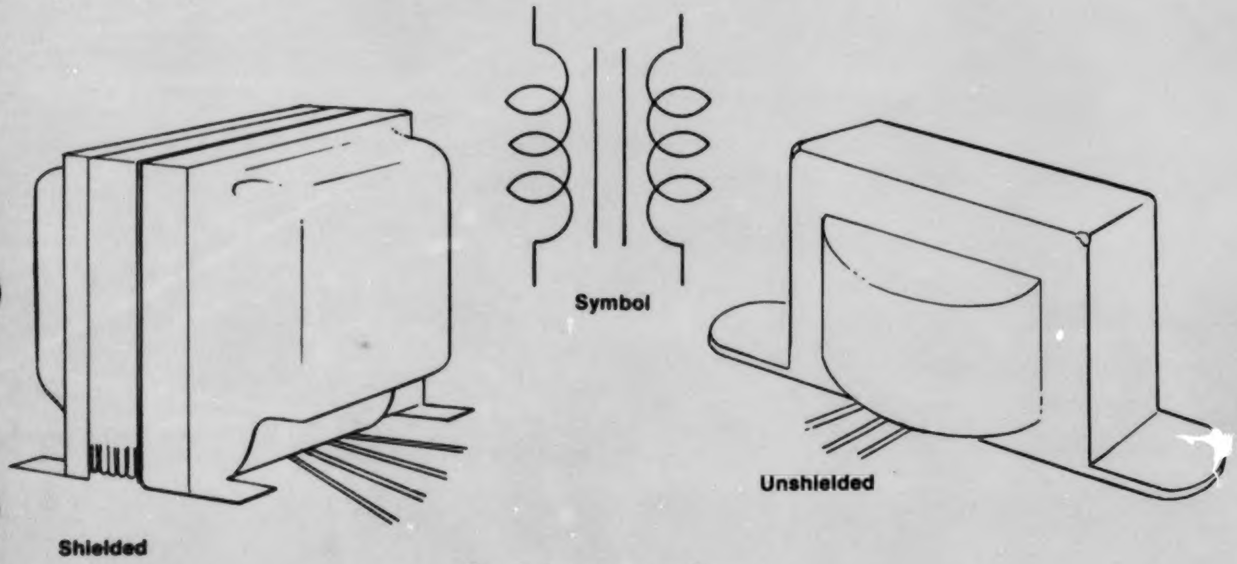


Fig. 3. Iron-core transformers

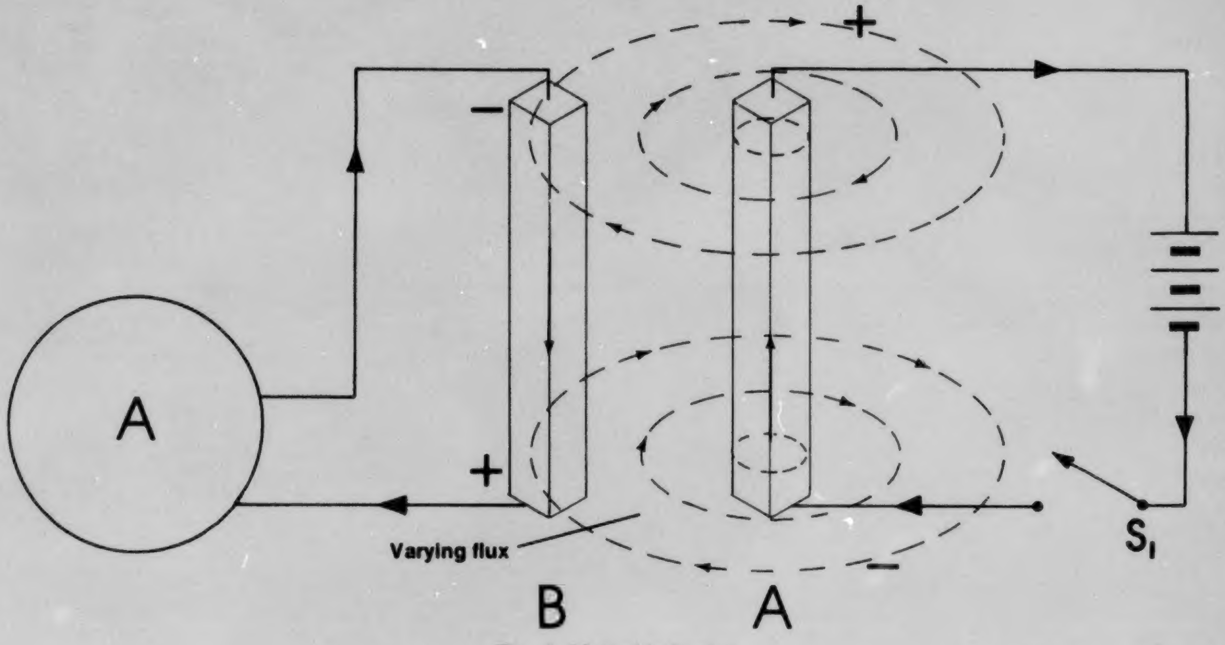
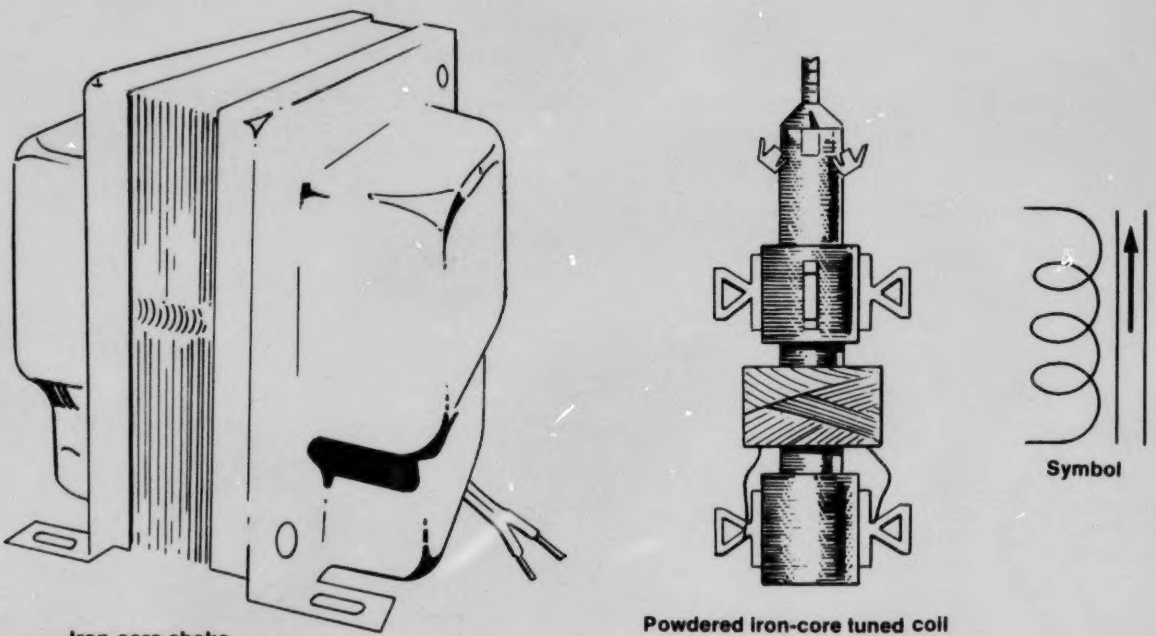
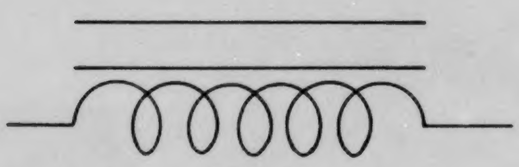

+
−
A
+
−
Varying flux
B
A
S₁

Fig. 4. Mutual induction



Iron-core choke

Powdered iron-core tuned coil



Symbol

Fig. 5. Iron-core choke and symbol; powdered iron-core tuned coil and symbol

or a contraction of the magnetic field about it. A current of varying strength will cause the flux to alternately expand and contract, inducing a voltage in the conductor and in nearby conductors. This demonstrates the principle of the transformer.

The Unit of Inductance

The property of an electrical circuit to oppose a change in current flow is called *inductance*. This opposition creates an induced voltage. The unit used to measure inductance is the *henry*.

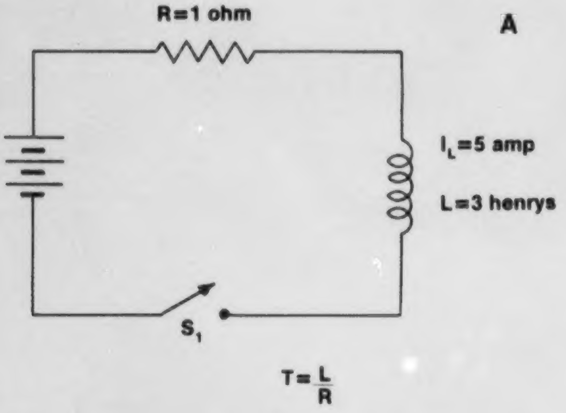
Resistance and Inductance Circuit Time Constant

Many circuits in radios and televisions use coils as a circuit component. Two different types of coils, and their *schematic symbols*, are shown in figure 5. It is important to understand their basic operation before you try to service these circuits.

The circuit in figure 6A has a 1-ohm resistor and a 3-henry coil in series with a DC voltage source. The schematic symbol (+) ⊣ | | | | ⊢ (−) for a battery always designates the positive terminal as the long line ⊣ and the negative terminal as the short line ⊢ in electronic circuits. Since electrons flow from negative to positive, the current travels first to the coil when the switch S_1 is closed (turned on). The current does not build up to its maximum value of 5 amp at once. The current is held back by the *counter voltage* that has developed in the coil. This *time delay* can be calculated for each R L circuit. The formula T = L/R is used to find the time constant in seconds. For the R L circuit in figure 6A, T = 3 henries/1 ohm = 3 seconds.

In figure 6B, the current buildup curve is shown from 0 to the maximum current of 5 amp. The time is shown in units of 3 seconds for each of five time constants from 3 to 15 seconds. In the first *time constant* of 3 seconds, the current rises to 63.2% of its maximum value, or 3.16 amp.

In the second time constant, the current rises 63.2% of the remaining amount of amperes. The remaining amount of amperes (1.84) is arrived at by subtracting the 3.16 amp (the point on the graph reached during the first time constant) from the maximum value of 5 amp. This remaining amount of



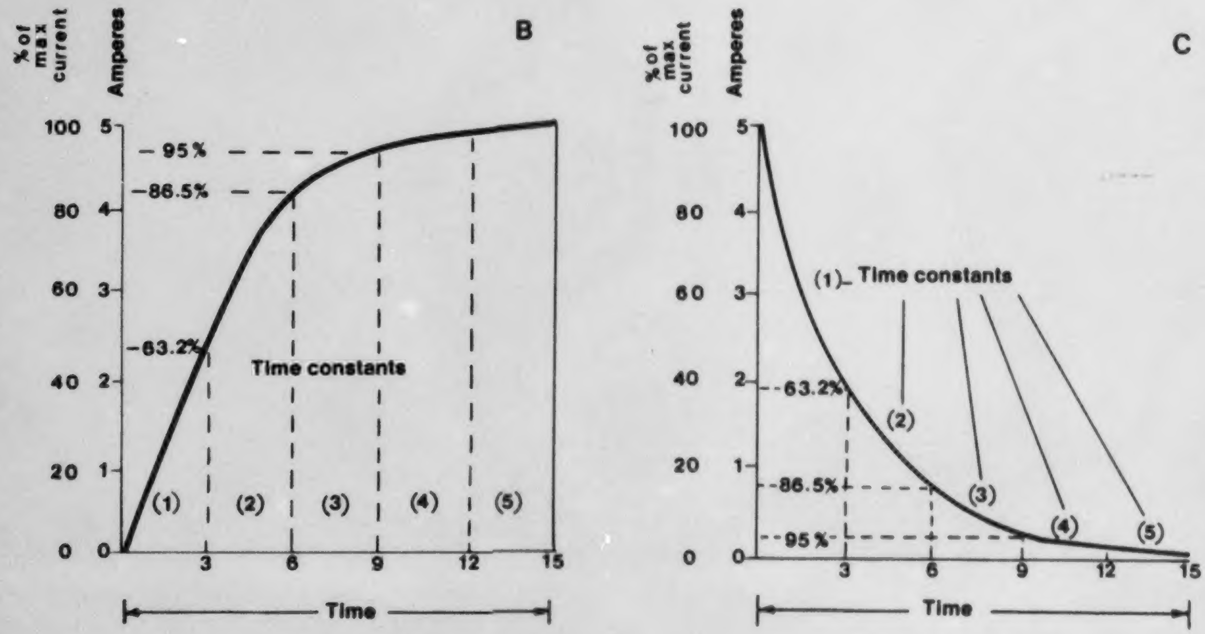


Fig. 6. A: *R L time constant circuit;* B: *current buildup;* C: *current decay*

1.84 amp is multiplied by the constant number 0.632 (63.2%) to give 1.163 amp. The 1.163 is added to the 3.16 amp, which is the value reached at the end of the first time constant. The total of 4.32 amp is 86.5% of the maximum current of 5 amp. Study the graph carefully. You will see that at the end of the second time constant at the point where the curve reaches 6 seconds, it has reached the values to the left of 86.5% and about 4.32 amp.

By the end of the third time constant, the current reaches 95% of its maximum value. The current rises 63.2% of the remaining current left on the graph. This remaining value is between 4.32 amp and 5 amp. Subtracting 4.32 from 5 gives a remaining amount of 0.68 amp. The 0.68 amp is multiplied by the constants 0.632 (63.2%), and the product is found to be 0.43 amp. The 0.43 is added to the present position of the current rise on the graph, which is 4.32 amp. This results in an answer of 4.75 amp, and this new point on the graph is 95% of the maximum value.

The same process using the constant of 63.2% continues through the fourth and fifth time constants. The *time constant* of the circuit refers to the recurring 63.2% of the rise or fall of current in a fixed interval of time. In the fourth interval of time, the current reaches 98.2% of maximum value. At the end of the fifth interval, it reaches about 99.3% of maximum value. Although the current buildup has not quite reached 100%, five time constants are considered to be all that is necessary.

Now regarding the circuit in figure 6A, assume that switch S_1 is opened again to its original position, thus taking the battery out of the circuit. The 5 amp (maximum current) does not immediately drop to zero, but gradually decreases as shown by the curve in figure 6C. At the end of the first time constant, the current drops 63.2% from its maximum value of 5 amp. It falls 0.632 × 5, or 3.16 amp. Now the maximum value of 5 amp minus 3.16 amp leaves the current at 1.84 amp by the end of that first time constant.

The second time constant ends with the current having decreased 86.5% from its maximum value, and by the end of the third time constant it has decreased 95% from the maximum value. Now you can see that there is not enough room left on the graph in figure 6C to show the values at the ends of the fourth and fifth time constants. By the end of the fifth time constant the current decay has dropped to a level that is so close to 100% that it is considered to be 100%. Five time constants are enough to demonstrate the way that the current decays in an inductive circuit.

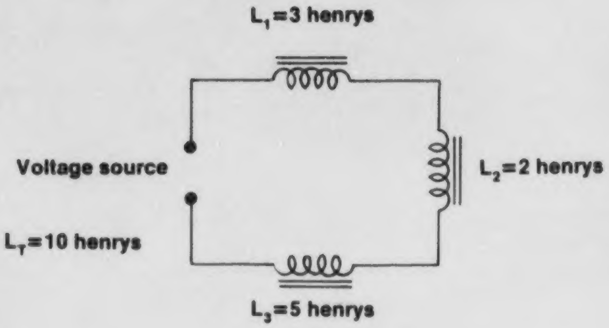


Fig. 7. Inductors in series

Inductors in Series Add Up to the Total Inductance

When three coils are placed in a circuit as in figure 7, there is no mutual induction to be considered because the coils are not coupled together. If L_1 is 3 henrys, L_2 is 2 henrys, and L_3 is 5 henrys, the total inductance (L_T) of the series circuit would be 10 henrys. The formula for inductors in series is:

$$L_T = L_1 + L_2 + L_3 \ldots + L_n$$

Inductors in Parallel with No Coupling

The formula that is used for inductors in parallel is the same as for resistors in parallel. If two or more inductors are placed in a parallel circuit as in figure 8, the formula to find the total inductance L_T is as follows:

$$L_T = \frac{1}{\frac{1}{L_1} + \frac{1}{L_2} + \frac{1}{L_3} + \ldots}$$

For only two inductors in parallel, a simplified equation may be substituted:

$$L_T = \frac{L_1 L_2}{L_1 + L_2}$$

When, as in figure 9, L_1 is 3 henrys and L_2 is 6 henrys, the total inductance L_T is 2 henrys.

$$L_T = \frac{L_1 L_2}{L_1 + L_2} = \frac{3 \times 6}{3 + 6}$$

$$= \frac{18}{9} = 2 \text{ henrys}$$

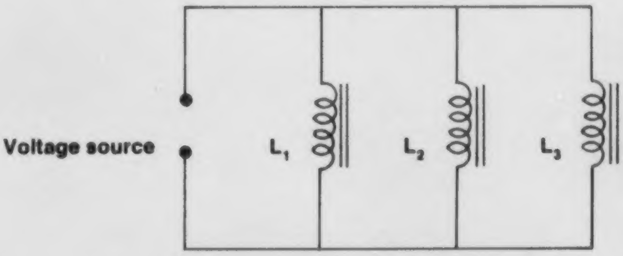


Fig. 8. Two or more inductors in parallel

Inductive Reactance

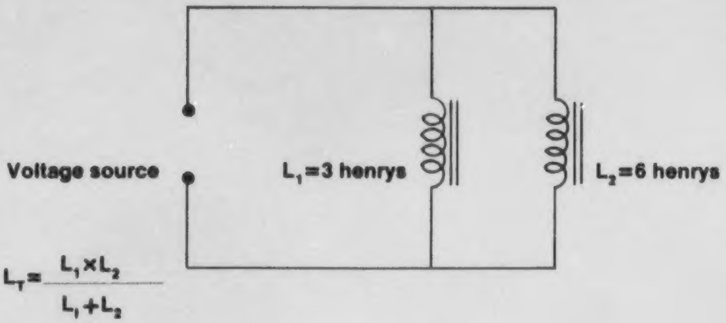
When an alternating current (AC) is used in a resistive circuit, all of the Ohm's law relationships are the same as they were for a direct current (DC) circuit. If inductance is used in an AC circuit, these relationships are no longer completely true. There is a *phase difference* between current and voltage in an AC inductive circuit. In an inductive circuit, the current *lags* the voltage by 90°. This is shown in figure 10. You must remember that an inductor opposes a change of current. The current does not reach its maximum value until after the voltage. There will always be a lagging current through an inductor.

In an AC inductive circuit, the term *inductive reactance* (X_L) is substituted for resistance in coils. Inductive reactance is the total opposition to the flow of alternating current that is caused by the inductor. The ohm (Ω) is the unit of measure for inductive reactance. To determine X_L, use this formula:

$$X_L = 2\pi f L$$

The symbol π represents the number 3.14. Substituting this in the formula and multiplying it by 2 gives 6.28, which is a constant that can always be substituted for 2π. If the frequency (f) of an alternating current is 10,000 cycles per second and the inductance in the circuit is 5 henrys, you can find X_L by substituting the numbers in the formula:

$$\begin{aligned} X_L &= 2\pi f L \\ &= 6.28 \times 10 \times 10^3 \times 5 \\ &= 62.8 \times 10^3 \times 5 \\ &= 314 \times 10^3 \text{ ohms} \end{aligned}$$



$$L_T = \frac{L_1 \times L_2}{L_1 + L_2}$$

Fig. 9. Only two inductors in parallel

AC Circuit Impedance

A very important term that is directly related to radio and television circuits is *impedance*. The circuit impedance (Z) for an inductive circuit can be defined as the total opposition to the flow of current in the circuit. This opposition includes both resistance and reactance in the circuit. To find the series or series equivalent circuit impedance for inductive circuits, use this formula:

$$Z = \sqrt{R^2 + X_L^2}$$

where Z = impedance, in ohms

R = resistance

X_L = inductive reactance

Assume that R is 8 ohms and X_L is 6 ohms. Put these numbers in the formula to find the solution.

$$\begin{aligned} Z &= \sqrt{R^2 + X_L^2} = \sqrt{8^2 + 6^2} \\ &= \sqrt{64 + 36} \\ &= \sqrt{100} = 10 \text{ ohms} \end{aligned}$$

A number squared (like R^2) means the number is multiplied times itself. When you find the square root ($\sqrt{}$) of a number, you must find the number that may be multiplied by itself (for example, $\sqrt{100} = 10$ because 10×10 is equal to 100).

Exercise

1. What is the principle of electromagnetic induction?
2. What is mutual induction?
3. What is inductance?
4. What is the formula for finding the time constant in an inductive circuit?
5. What is the formula used for inductors in a series circuit?
6. Give two formulas that are used for inductors in a parallel circuit.
7. Give the two formulas used for series and parallel resistive circuits.
8. How can you use the resistance and the inductive reactance to find the impedance in an inductive circuit?

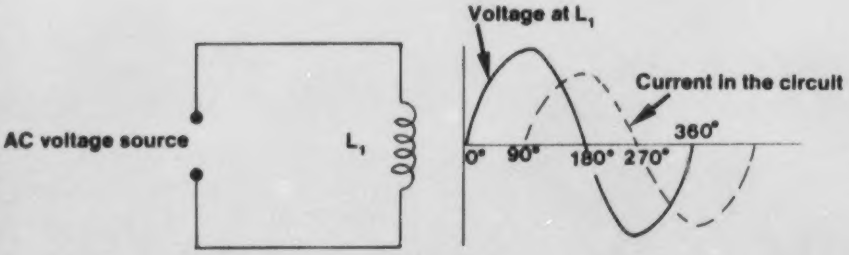


Fig. 10. AC inductive circuit

C-5

Capacitance

Objectives: After completing this assignment, you should be able to—

1. compare the reaction of current and voltage in capacitive circuits to their reaction in inductive circuits;
2. compare capacitor action with a DC voltage source to capacitor action with an AC voltage source;
3. compare the R C time constant to the R L time constant;
4. define *capacitive resistance*;
5. define *impedance*;
6. give the basic formulas for capacitors connected in series and capacitors connected in parallel; and
7. describe eight types of capacitors mentioned in this assignment.

In its simplest form, **a capacitor is two conductors with a nonconductor between them**. The nonconductor is called a *dielectric*.

The most important property of a capacitor is its *ability to store current*. To understand how this happens, refer to figure 1. Assume that there is no charge on plates P_1 and P_2. Before the switch (S_1) is closed to complete the circuit, the plates will be at zero potential. Because there is an open circuit, no voltage is present. When S_1 is closed, as shown in figure 1, the current instantly reaches its maximum value. This is not the same with the action of the voltage. When the switch was closed, P_1, which is connected to the negative terminal of the battery, became negatively charged. P_2, which is connected to the positive terminal of the battery, became positively charged. The voltage does not, however, jump immediately to the maximum value (whatever the value of voltage from the battery), but gradually increases until it reaches 6 volts. The battery acts as a pump forcing electrons off of P_1. An excess of positive ions gathers on P_2 while an excess of electrons are on P_1. During the time that this unbalanced condition of ions exists, current flows in the circuit. After the current reaches maximum, it begins to decrease and continually decreases until it reaches zero. The current becomes zero at the same instant that the two plates have reached the maximum value of 6 volts. In a capacitor, while the current is decreasing, the voltage is building up. This is the opposite reaction to that of the inductive circuit. An *inductor* opposes any change in *current* in a circuit. A *capacitor* opposes any change in *voltage* in a circuit.

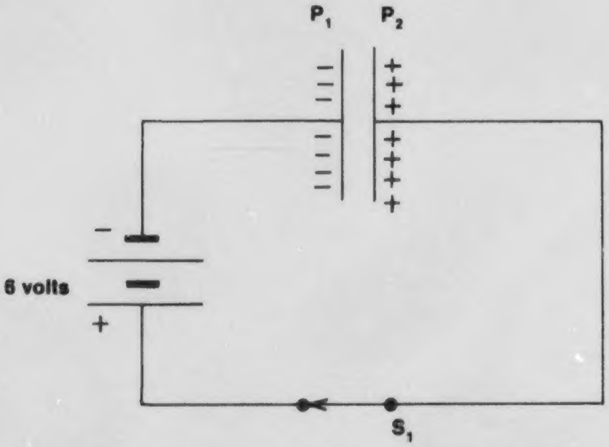


Fig. 1. Basic capacitive circuit (with switch closed)

Definition of Capacitance

Capacitance can be defined as the *property of a circuit to oppose a change in voltage*. The **farad** is the unit of measure for capacitance. When a capacitor is charged with one coulomb of electrons and its plates have a potential difference of one volt, it has a capacitance of one farad. It is not practical in radio and television work to use such a large unit as the farad. The *microfarad* (µf), which is one millionth of a farad, is more commonly used.

Capacitor Action with Direct Current

You have seen how a capacitor charges when placed in the series direct current circuit of figure 1. For a capacitor to discharge, the charge on the plates must be neutralized. Assume that in figure 2, S_1 is placed in position 2. This takes the 6-volt battery out of the circuit, and allows the excess electrons on P_1 to flow through the circuit to the positive plate P_2. The capacitor continues to discharge in this manner until the charge is ***neutralized***. A capacitor does not consume power. The energy taken from the source is returned when the capacitor discharges.

R C Time Constant

In electrical circuits containing resistance and capacitance, the time constant (TC) is equal to the resistance (R) multiplied by the capacitance (C), or TC = R × C. The time constant is the time required for a capacitor to reach about 63.2% of the maximum voltage that is available in the circuit. By the end of the first time constant, the capacitor charges to 63.2% of the maximum voltage. During the second time constant, the capacitor charges to 63.2% of the remaining voltage. This brings it to 86.5% of maximum. During the third time constant, it charges another 63.2% of the remaining voltage, which is 95% of maximum value. At the end of five time constants, the capacitor is considered to be fully charged. This is shown graphically in figure 3. It is important to note that these same curves could be used for the current buildup and decay in an R L circuit. The only difference in the action involved is that for R L circuits the curves are for the current, and for R C circuits the curves fit the voltage.

Capacitor Reaction with Alternating EMF

You remember that in figure 1, when a DC voltage source was used, the current continued to flow until the voltage between plates P_1 and P_2 was built up to the same voltage as the battery. At that time the current was zero.

When an alternating emf is applied, as in figure 4, the charge on plates P_1 and P_2 changes repeatedly. No current actually flows through the dielectric between the plates, but it is constantly flowing in the rest of the circuit from P_1 to P_2.

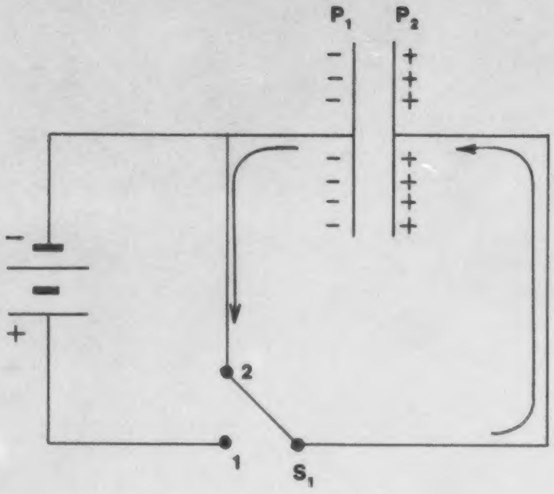


Fig. 2. Basic capacitive circuit (with switch open)

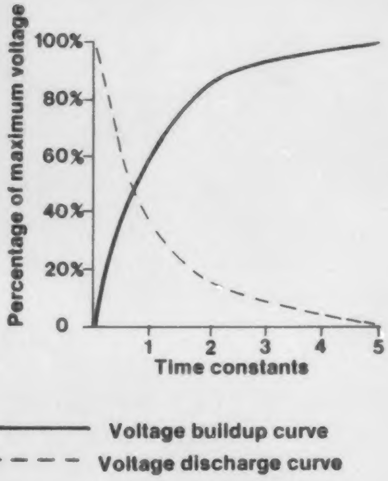


Fig. 3. R C time constant

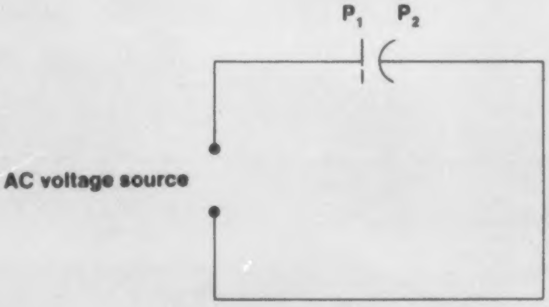


Figure 4

The voltage and current curves shown in figure 5 illustrate the relationship between current and voltage in a capacitive circuit. Notice that at 0 when the voltage sine wave curve is beginning, the current has already moved a positive 90 electrical degrees. In the previous AC inductive circuits, the current lagged the voltage by 90°. But in the capacitive circuit, voltage lags the current by 90°.

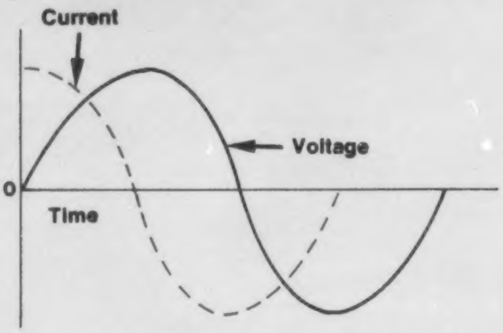


Fig. 5. Voltage and current in a capacitive circuit

Capacitive Reactance

You learned about inductive reactance in Assignment C-4 and how to calculate its value. *Capacitive reactance* is the opposition to the flow of alternating current that it is presented by a capacitor. Capacitive reactance may be found with this formula:

$$X_C = \frac{1}{2\pi fC}$$

where:

X_C = capacitive reactance, in ohms
2π = the constant 6.28
f = frequency, in cycles per second (or hertz)
C = capacitance, in farads

Solve this problem to be sure you understand how to use the formula. What is the reactance at 200K cycles, for a 0.03 μf capacitor?

$$X_C = \frac{1}{2\pi fC}$$

$$= \frac{1}{6.28 \times 2 \times 10^5 \times 3 \times 10^{-8}}$$

$$= \frac{1}{37.68 \times 10^{-3}} = \frac{1}{.037}$$

$$= 27.03 \text{ ohms}$$

Impedance

The capacitive circuit impedance can be defined as the total opposition to the flow of current in the circuit. The opposition includes both resistance and reactance. To find the series or series equivalent circuit impedance for capacitive circuits, use this formula:

$$Z = \sqrt{R^2 + X_C^2}$$

Where there is resistance, inductance, and capacitance in a series circuit, the impedance is found with this formula:

$$Z = \sqrt{R_2 + (X_L - X_C)^2}$$

If X_C is larger than X_L, use this formula:

$$Z = \sqrt{R_2 + (X_C - X_L)^2}$$

Capacitors in Series

The capacitance for series capacitors is calculated using the same formula (substituting capacitance for inductance) as the one used for parallel inductors.

$$C_T = \frac{1}{\frac{1}{C_1} + \frac{1}{C_2} + \frac{1}{C_3} + \ldots \frac{1}{C_n}}$$

When two capacitors are placed in a series circuit, the more simplified formula can be used:

$$C_T = \frac{C_1 C_2}{C_1 + C_2}$$

In the case of equal value capacitors in series, divide the value of capacitance by the number of capacitors. It is also important to note that the working voltages of capacitors in series add up to the total voltage. A TV service technician may need to use two 50-volt capacitors to replace one rated at 100 volts.

Capacitors in Parallel

To find the total capacitance (C_T) of capacitors that are connected in parallel, simply add the values.

$$C_T = C_1 + C_2 + C_3 + \ldots + C_n$$

Types of Capacitors

Capacitors, like resistors, are manufactured in two main types—*variable* and *fixed*. A variable-type capacitor like the ones used in radio and television tuners is shown in figure 6. Another variable type is the *trimmer* capacitor (fig. 7). These capacitors are adjusted by using a screwdriver on the small adjustable setscrew.

A capacitor that is very important in the proper operation of radio and television sets is the *electrolytic* capacitor (fig. 8). These capacitors are used largely as filter capacitors in power supplies of radio and television sets. They are also used often as coupling capacitors in transistorized audio circuits. Figures 9 and 10 show other shapes of capacitors used in radio and television sets.

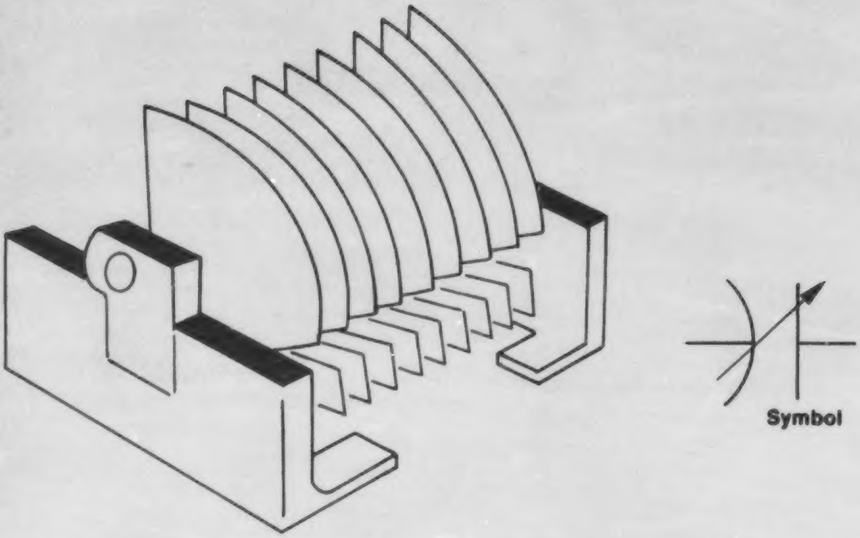


Fig. 6. Variable capacitor

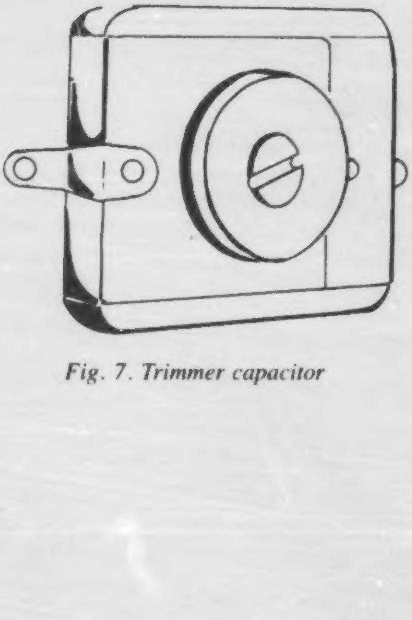


Fig. 7. Trimmer capacitor

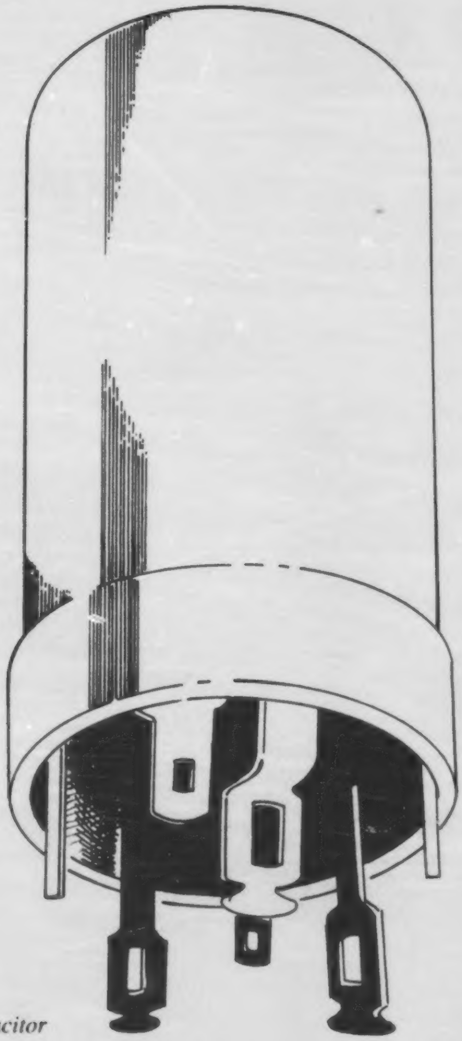


Fig. 8. Electrolytic capacitor

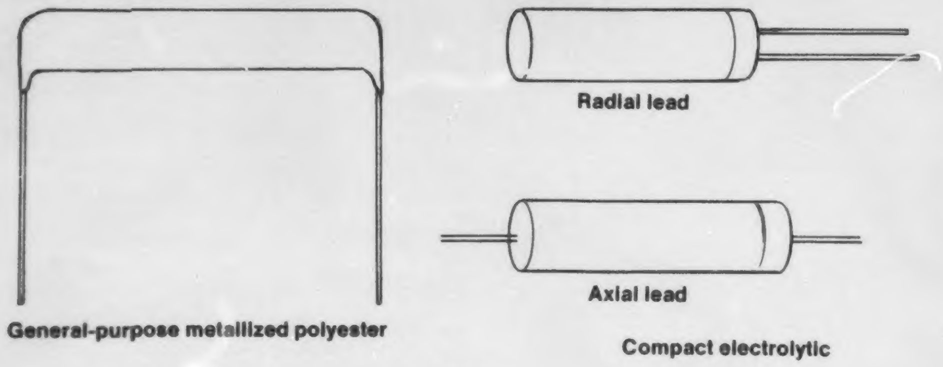

Radial lead
Axial lead
General-purpose metallized polyester
Compact electrolytic

Fig. 9. Types of capacitors

Exercise

1. How do current and voltage in an AC capacitive circuit differ from current and voltage operating in an AC inductive circuit?
2. How is capacitor action in a DC circuit different from capacitor action in an AC circuit?
3. What is the difference between the R C time constant and the R L time constant?
4. What is *capacitive reactance*?
5. What is *impedance*?
6. What is the main formula for capacitors in series?
7. What is the formula for capacitors in parallel?
8. Describe the eight types of capacitors shown in figures 6 through 10.

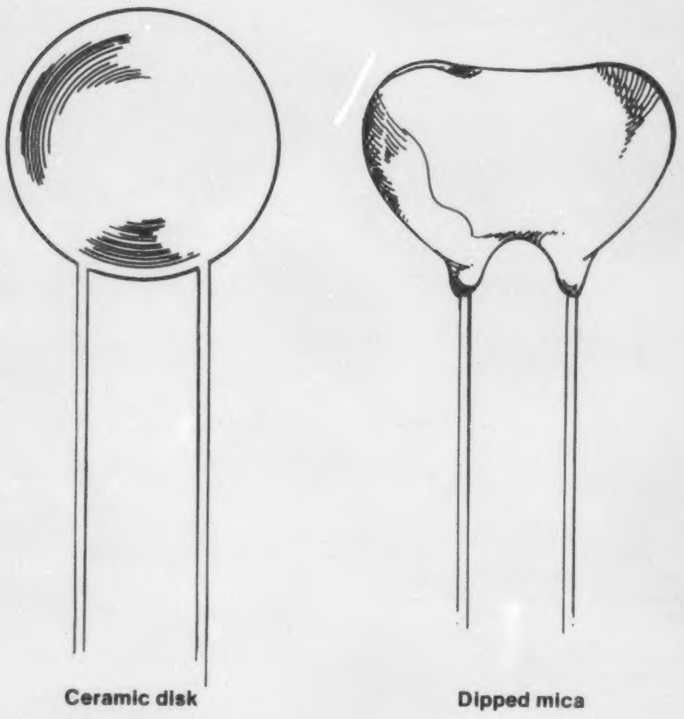

Ceramic disk
Dipped mica

Fig. 10. Types of capacitors

Section

D

Operation of Volt-Ohm-Milliammeter (VOM)

D-1. Basic Electrical Meter Movement and Current Measurement
D-2. The Voltmeter Function
D-3. The Ohmmeter Function
D-4. Basic Circuit Testing
D-5. VOM Accessories—High-Voltage Probes and Radio-Frequency Probes

Objectives: After completing this assignment, you should be able to—

1. explain the d'Arsonval meter movement;
2. tell what VOM meter sensitivity is;
3. tell how the ammeter is protected from damage from too much current;
4. tell how resistors are used in the meter circuit for measuring current; and
5. read a typical ammeter scale and record the values for several different levels of current in electrical circuits.

D-1

Basic Electrical Meter Movement and Current Measurement

The Basic Meter of the Volt-Ohm-Milliammeter (VOM)

You should remember this basic fact about all VOM multimeters. No matter what is being measured in an electrical circuit, it is the *current in motion* through the meter movement mechanism that makes the pointer move. The *full-scale measurement* is the maximum point of travel that the pointer needle can reach from zero.

It is necessary to have an arrangement of switches on the front of the VOM, as shown in figure 1. The function switch must be placed in the current measuring position to begin with. The next step in measuring current is to turn the range switch to the highest range, if you are not sure of how much current to expect in the circuit under test. If the needle does not move in that range position, continue to move the range switch downward until the needle deflects. The needle should come to rest. The value of the current in microamperes can then be read on a meter scale like the one in figure 2.

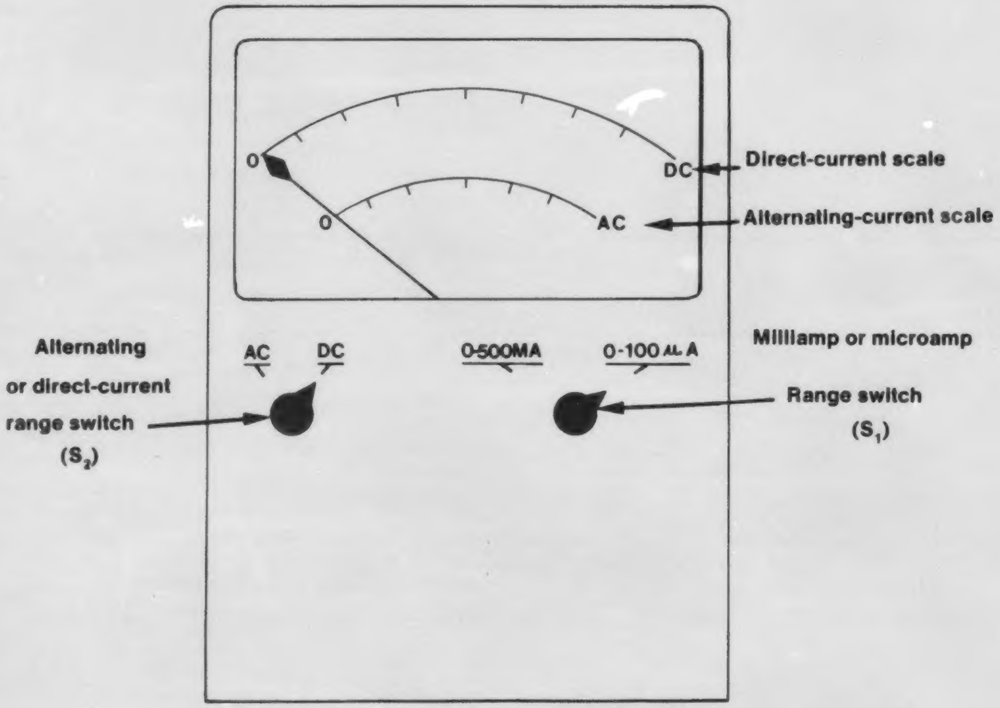


Fig. 1. Current-measuring function of VOM meter

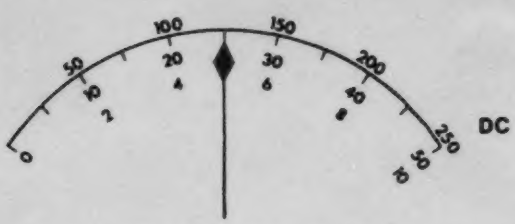


Fig. 2. Reading the current on a VOM meter

The Meter Movement

The principle of the d'Arsonval movement is used in most VOMs. Assume that a *movable coil* is positioned between the north and south poles of a permanent magnet, as in figure 3. A pointer is attached to the top of the coil so that it points to the meter scale. When special test prods (see fig. 4) are plugged into the test lead terminals and the metal tips of the prods touch a *hot wire* (conductor carrying current), current flows through the movable coil. The current creates a magnetic field around the coil with a definite polarity set up at either end of the coil. Assume that the pointer and the coil are held at the zero position by a coiled spring attached to the pivot point. When current flows through the coil, it moves the pointer because of attraction and repulsion between the poles of the coil and the poles of the permanent magnet.

The deflection of the pointer caused by the magnetic field of the movable coil is proportional to the amount of current flowing through the coil. The larger the value of current, the greater the force that turns the coil.

VOM Sensitivity

The *full-scale sensitivity* of a meter refers to the amount of current required to deflect the meter pointer full scale. The more sensitive the meter is, the smaller the amount of current required for full-scale deflection. A reasonably sensitive meter might be expected to handle 40 or 50 microamperes.

The *sensitivity rating* of a VOM meter is usually shown in *ohms per volt* on the face of the meter. The higher the value of ohms, the more sensitive the VOM. To find the sensitivity of a VOM meter, the total circuit resistance is divided by the total voltage required for full-scale deflection. For example, assume that a 20-volt battery as the power source and an ammeter are connected in series. The ammeter has an internal resistance (R_m) of 10K ohms (10,000 ohms), and 40 μA (microamperes) of current are required for full-scale deflection. By dividing 10K ohms by 20 volts (R_m/E), you can determine that the sensitivity is 500 ohms. This would not be considered to be a very sensitive meter. For general purpose radio and television circuit testing, a meter of at least 20,000 ohms per volt would be more desirable. The cheaper models would usually be at least 1,000 ohms per volt. This sensitivity rating that is referred to is a direct current (DC) rating. This is more important than the alternating current (AC) rating. Often the AC rating is also printed on the face of the meter. The DC sensitivity is always a larger number. For example, for a DC sensitivity of 20,000 ohms per volt, you should expect to see an AC sensitivity of about 1,000 ohms per volt. It is important to remember that for radio and television circuit testing, when voltage measurements are made *across a high resistance or high impedance, a high-sensitivity VOM meter is needed.*

Shunt Resistors Protect the Ammeter and Increase the Meter Range

If too much current flows through a meter, the coil may burn out. The meter is a very delicate mechanism. To protect it from damage, a resistor is placed in *shunt* (parallel) with the meter, for every range of current that is provided by the range switch (see fig. 5). VOM meters vary in their ranges. Some meters have a range that is provided to read current values of 10 amp or higher. To be useful to a radio and television service technician, a VOM meter should have provisions

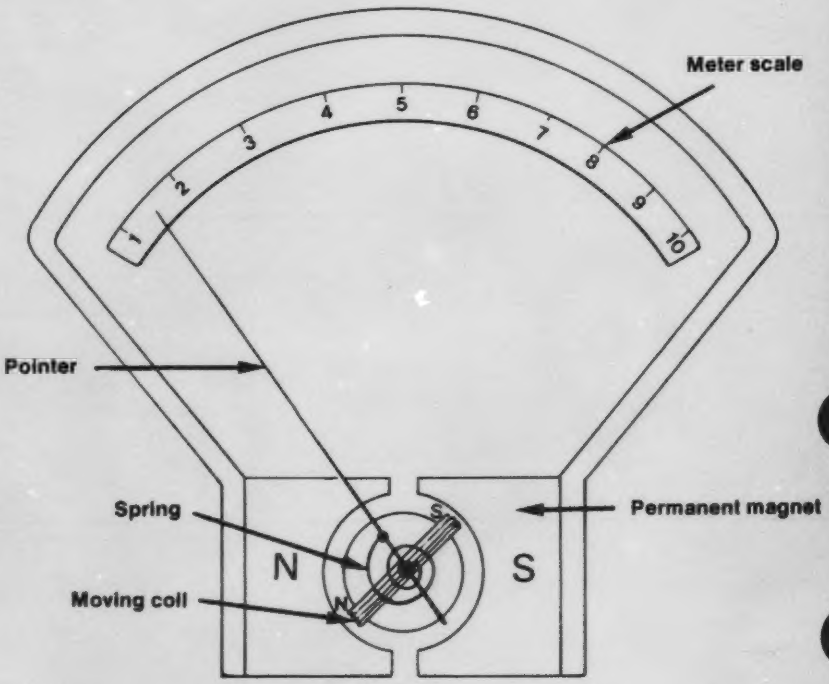


Fig. 3. d'Arsonval meter movement

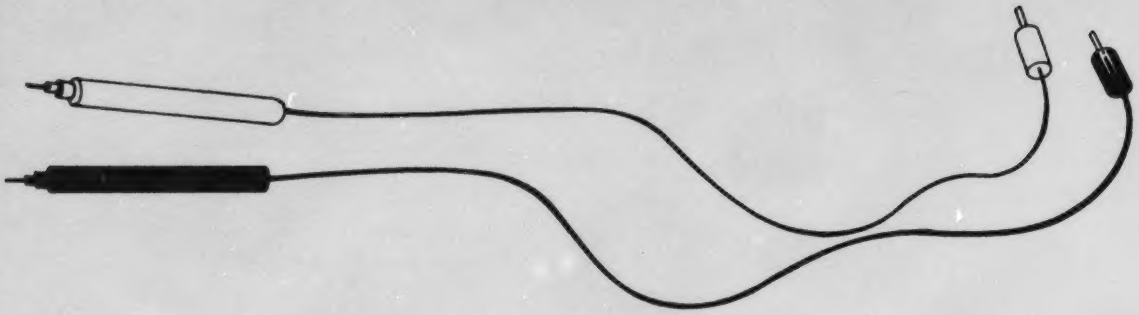


Fig. 4. Meter test prods

for measuring current in milliamperes (thousandths of an amp) and in microamperes (millionths of an amp) on a VOM meter. The symbol for milliamps is MA, and the symbol for microamps is μA. These symbols are used on the meter to make it easier to read and to save space.

Assume that the correct ohmage value is chosen for R_1 in figure 6 to cause 9 microamperes of current to flow through it. One microampere is left to flow through the meter to deflect the needle full scale without damaging the meter. The value of R_2 is chosen so that it will allow 49 microamperes to flow through it and 1 microampere to flow through the meter. The value of R_3 is chosen so that it will allow 99 microamperes to flow through it and 1 microampere to flow through the meter.

Now, with the needle deflected exactly one half scale and with S_1 in the position shown in figure 5, read the current value shown in figure 2. On most VOM meters, the same numbers used on a scale must be used for several ranges. For example, the maximum values shown on the scale in figure 2 are 10, 50, and 250. For the 0–100 microamp range, you would use the 0–10 scale as though it were the 0–100 scale. When the 0–10 scale is converted to the 0–100 scale, each main division of the scale is considered to be 10 microamperes. Each of the smallest divisions is equal to 2 microamperes. The current value shown by the needle in figure 2 is 50 microamperes.

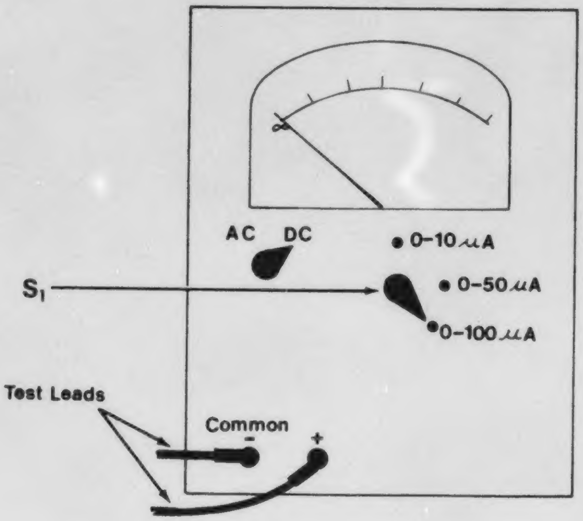


Fig. 5. Meter case showing external position of switch (S_1)

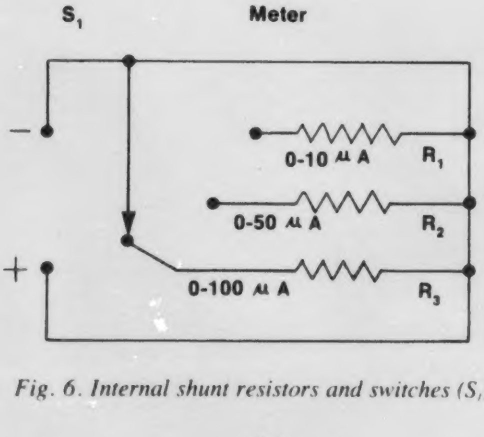
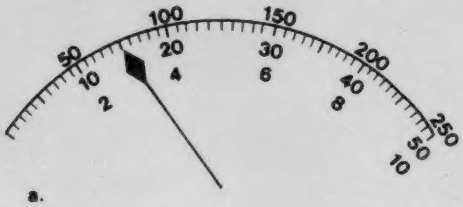


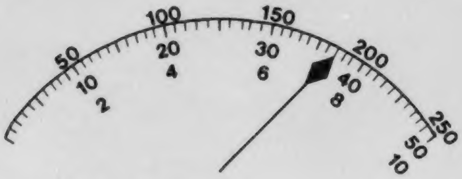
Fig. 6. Internal shunt resistors and switches (S_1)

Exercise

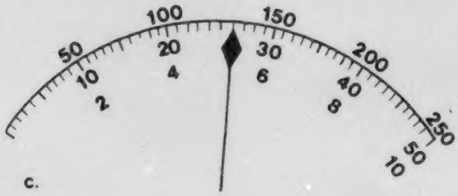
1. How does the d'Arsonval meter movement operate to measure current in a VOM meter?
2. What is VOM meter sensitivity?
3. What protective measures have been taken in the design of the ammeter function of the VOM to prevent damage from too much current?
4. In what way are resistors used in the internal meter circuit to measure current?
5. What are the values of current in microamperes (use the 0–100 μA scale) for the following pointer indications?


50
100
150
200
250
10
20
30
40
50
2
4
6
8
10

a.


50
100
150
200
250
10
20
30
40
50
2
4
6
8
10

b.


50
100
150
200
250
10
20
30
40
50
2
4
6
8
10

c.

Objectives: After completing this assignment, you should be able to—

1. discuss the basic functions of a voltmeter;
2. tell about the circuits inside the voltmeter case and how multiplier resistors are used; and
3. discuss voltmeter sensitivity.

D-2

The Voltmeter Function

The measurements of DC voltage and resistance are the most useful functions of a multimeter. Radio and television service technicians use the AC voltage function only occasionally to read AC voltages at audio (lower frequency/audible range) frequencies.

Voltage-measuring instruments are used to a much greater extent than current-measuring instruments. The reason is that it is not necessary to open the circuit to measure voltage, since voltages are measured in parallel with the circuit. Service technicians try to avoid the time-consuming process of measuring current in series with the circuit. Figure 1 shows the correct test lead positions for measuring voltage and for measuring current.

Multiplier Resistors

The same basic d'Arsonval meter, which you learned about in Assignment D-1, may also be used to measure voltage. A function switch on the front of the meter case allows you to switch to the voltage function. When this is done, a different circuit is placed in series with the coil of the meter. In this voltage-measuring circuit, a high resistance is placed in series with the meter for the lowest voltage range. This is placed inside the case with the meter circuit and is called the *internal resistance*. Resistors are placed in series for the higher voltage ranges and are connected externally. Figure 2 shows these series resistors in the external circuit. They are called *multiplier resistors*. These multiplier resistors are used to protect the meter from voltages over the limit of the meter. The meter is protected from damage during this voltage-measuring function in the same manner that the meter was protected by shunt resistors for the current-measuring function.

Sensitivity

The DC sensitivity of a voltmeter is determined by dividing the sum of the internal meter resistance (R_m) and the external series resistance (R_s) by the full-scale reading in volts. For example, if the sum of the internal and external resistances is 10 megohms (10 million ohms) and the full-scale reading is 500 volts, use this formula:

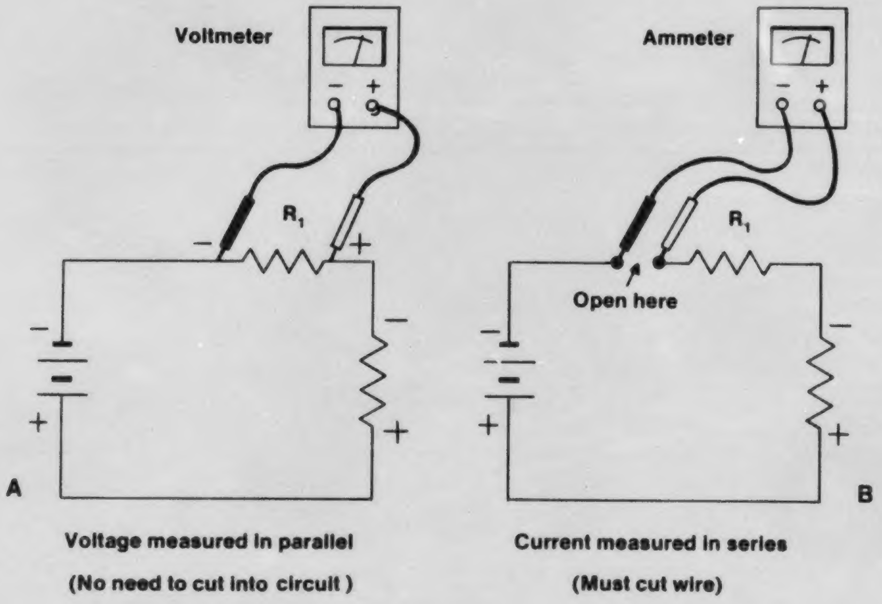

Voltmeter
R1
−
+
A
Voltage measured in parallel
(No need to cut into circuit)
Ammeter
R1
Open here
−
+
B
Current measured in series
(Must cut wire)

Fig. 1. Comparison of voltage and current measurement

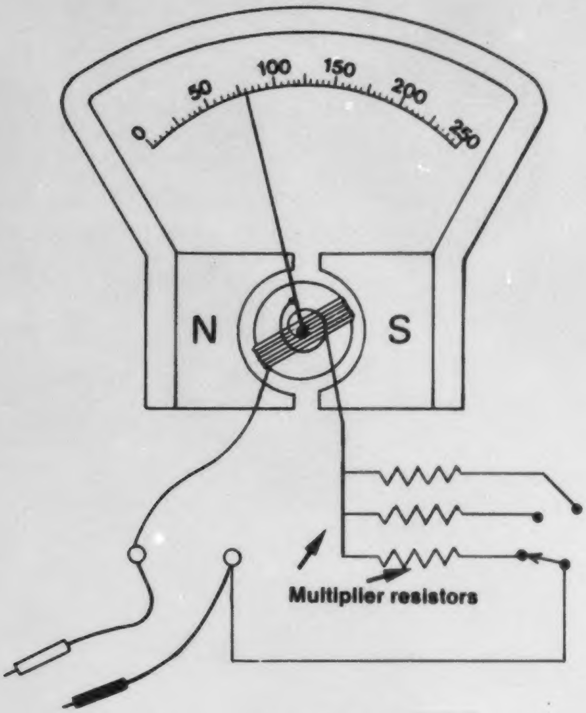

0
50
100
150
200
250
N
S
Multiplier resistors

Fig. 2. Basic voltmeter circuit with three ranges

$$\text{Sensitivity} = \frac{R_m + R_s}{E}$$

$$= \frac{10 \times 10^6}{500}$$

$$= 20{,}000 \text{ ohms per volt}$$

Look at the meter scales shown in figures 3, 4, and 5. Notice that figure 3 and figure 4 show the same meter scale to be read for DC and AC measurements of voltage. These are also the same scales you used to practice reading current in Assignment D-1. The internal design and the meter scales of most VOMs make this sort of simplification possible. The same scales are read for several different meter functions. You can see that there is only so much room on the meter face. The meter would be much harder to read if it were cluttered up with more scales.

Exercise

1. What functions of a voltmeter are most useful to service technicians?
2. What are multiplier resistors?
3. Why are multiplier resistors used?
4. What is voltmeter sensitivity?

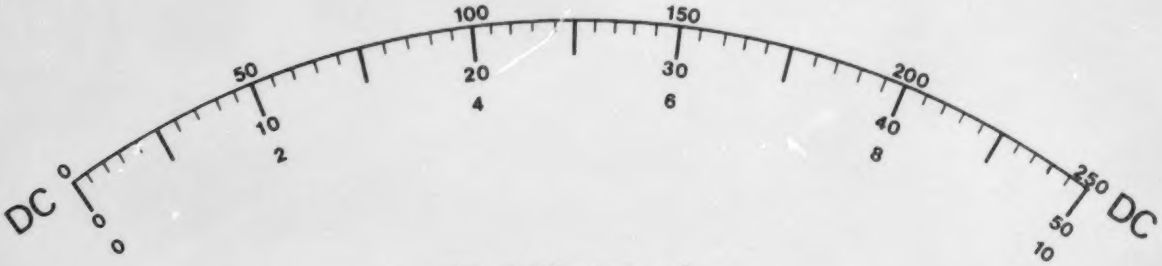

DC
0
50
100
150
200
250
0
10
20
30
40
50
0
2
4
6
8
10
DC

Fig. 3. DC voltage scale

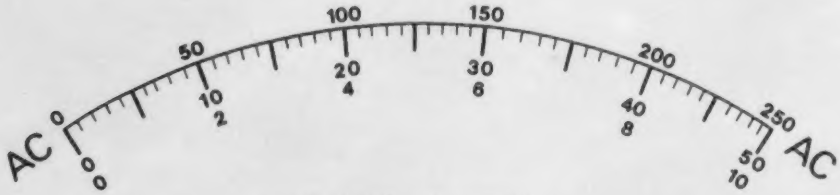

AC
0
50
100
150
200
250
0
10
20
30
40
50
0
2
4
6
8
10
AC

Fig. 4. AC voltage scale

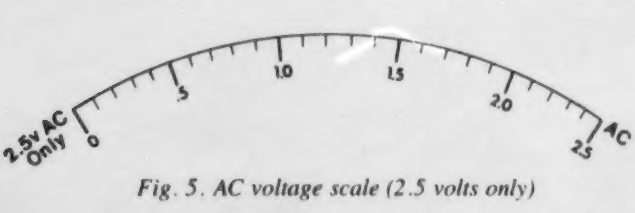

2.5v AC
Only
0
.5
1.0
1.5
2.0
2.5
AC

Fig. 5. AC voltage scale (2.5 volts only)

D-3

The Ohmmeter Function

Objectives: After completing this assignment, you should be able to—

1. explain the basic ohmmeter circuit;
2. discuss the operation of the ohmmeter to check for continuity in a circuit; and
3. tell how the ohmmeter is used to measure resistance.

The same basic DC milliammeter that is used to measure current and voltage is also used to measure resistance. A low-voltage battery (usually 3 volts) is added. The efficient operation of the ohmmeter depends on this direct current source. When the battery gets old and weak, it should be replaced.

A basic ohmmeter circuit is shown in figure 1. A small rheostat is provided so that the pointer can be adjusted to zero for every range of resistance. This is labeled on the meter case as the *zero adjust* mechanism. The front of an ohmmeter case includes the resistance range switch and the zero adjust dial, as shown in figure 2.

Resistance Measurement

When you measure a resistance, the meter test leads should first be shorted together. This causes the pointer to deflect to the extreme right side of the meter where the zero mark is located. While the leads are held together, the zero adjust mechanism is turned until the pointer is lined up even with the zero mark. Now the ohmmeter is ready to measure resistance or to test for continuity on that particular range. Ohmmeters usually provide several ranges from 1 ohm up to several megohms of resistance. When you are not certain how much resistance is to be measured, the range switch should be turned to the highest range. If the pointer does not deflect, the range switch should be turned down to the next range. This is continued until the pointer *does* deflect and the resistance in ohms can be read from the meter scale.

Resistance is measured or continuity tested with the *power off* in the circuit to be measured. If a circuit's operating voltage is applied to the meter, it could damage the meter movement. For this reason, when you are checking resistance or continuity in radio or television circuits, you must be certain the circuits are completely dead. And even though the power is off, be certain to discharge any capacitors located in the circuit to be tested. Touch the leads of capacitors with the metal blade of a screwdriver, or use a jumper wire to discharge them.

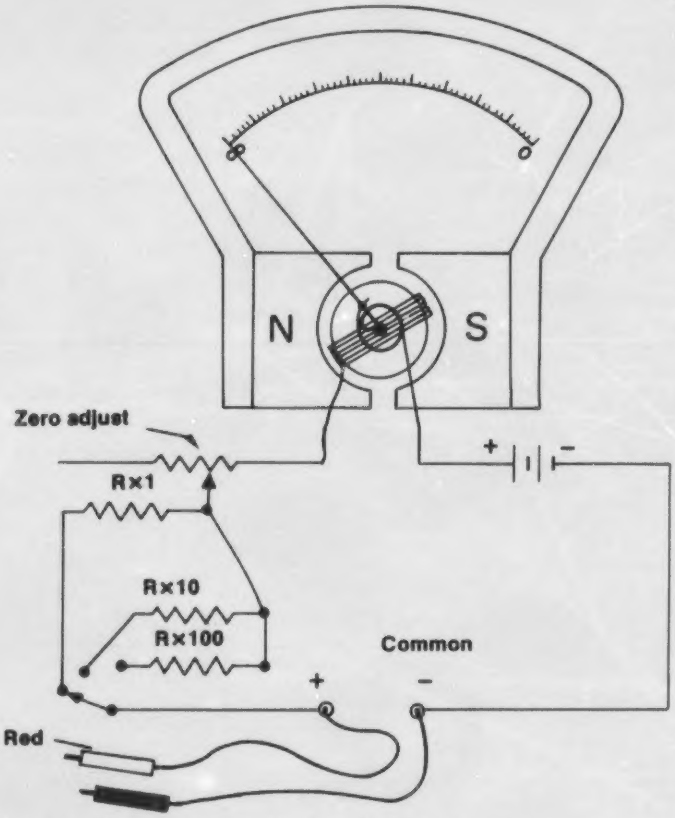


Fig. 1. Basic ohmmeter circuit

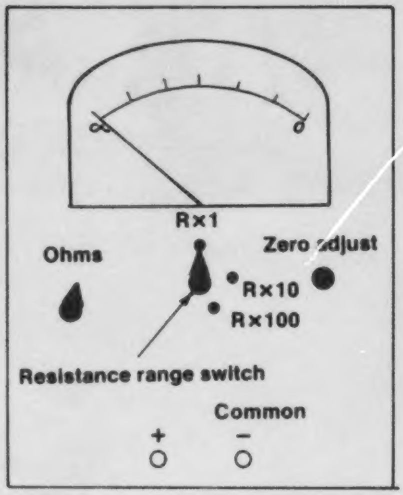


Fig. 2. Ohmmeter functions—front of case

Resistance Ranges and Multiplier Resistors

A multiplier resistor is provided in the ohmmeter circuit for each resistance range that it measures. The same principle is involved here that applied to the multiplier resistors used in the voltmeter function.

Correct Test Lead Connections

To measure a resistance on a particular range, the test leads must always be connected across the resistor. The test leads may also be connected across several resistors in series to measure total resistance.

Study the ohmmeter scale in figure 3 for a little while. This ohmmeter scale goes from zero (on the right) up to 2 megohms (2 million ohms) and from there to infinity (∞). The large divisions are 2, 5, 10, 15, 20, 30, 40, 50, 70, 100, 150, 200, 500, 1 meg, and 2 meg. From 0 to 5, the smallest divisions are 2 units. From 5 to 10, the large division is 1 unit and the small division is half a unit, or 0.5. From 10 to 20, the small divisions are 1 unit. From 20 to 30, the small divisions are 2 units. Notice that, between the other large divisions, some have 5 units, some have 10 units, some have 50 units, and some have 100 units.

Now, see if you can read the value in ohms for the resistance where the short arrow on the left is pointing. Assume that the range switch is pointing to R x 1. You should read 130 ohms.

Try another one. For the range of R x 100, read where the long arrow points. From the scale you should read about 3.7. You have to estimate because the pointer arrow points about halfway between 3.6 and 3.8. For the R x 100 scale, you must multiply 3.7 by 100 and you should get 370 ohms for the answer. Have your instructor lay a pencil as a pointer over the figure in different locations, and practice until you feel confident of your ability to read the correct ohmic values.

Exercise

1. What meter is used to measure resistance in an ohmmeter?
2. What sort of power source is used in the ohmmeter function?
3. How does the ohmmeter circuit operate?
4. How is an ohmmeter used to check for continuity in a circuit?
5. How is the ohmmeter used to measure resistance?

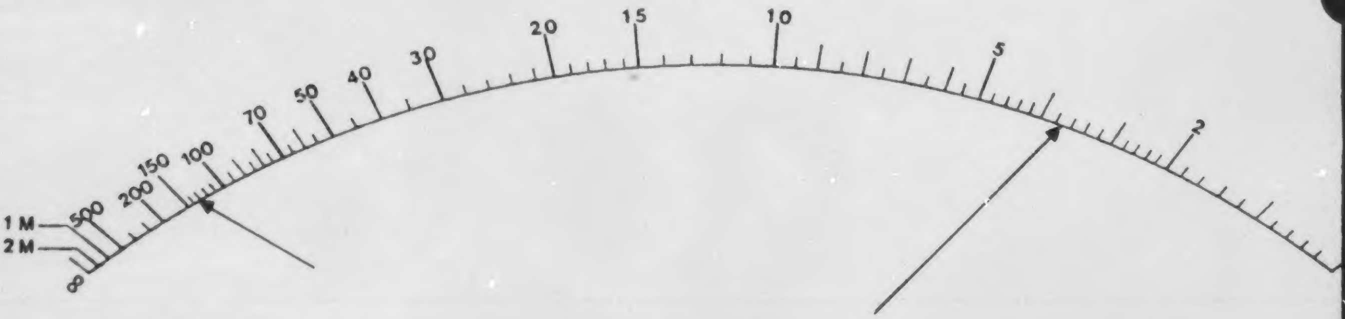


Fig. 3. Ohmmeter scale

D-4

Basic Circuit Testing

Objectives: After completing this assignment, you should be able to—

1. discuss the basic troubleshooting procedure that should be used to find a faulty circuit;
2. tell the correct procedure for testing a resistor in a circuit;
3. tell the procedure for checking the voltage specifications given in the manufacturer's data sheets; and
4. tell two ways that a VOM can be used to test current action in a circuit without cutting into the circuit to connect an ammeter.

The troubleshooting device that is most often used by radio and television service technicians is the ohmmeter. The reason for this is apparent when you think about how troubleshooting procedures must be carried on. To begin with, since there is already something faulty about the particular equipment being tested, it is best to try to find the trouble without energizing the equipment. And the ohmmeter is used with the power off.

Continuity and Resistance Tests with the Ohmmeter

Tests for continuity and resistance are the most valuable functions of a multimeter. Quite often the service technician can locate the trouble quickly, with only a general idea of what part of the equipment is at fault. For example, assume that a customer reports having smelled something burning at the back of the television set before both the sound and the picture went out.

The AC power line cord delivers alternating current to the power supply. When the power supply is not operating, the voltage and current needed at all the other sections of the equipment are not available. For this symptom of trouble, the set is completely dark and without sound. When the power line cord is plugged in and the switch is turned on, nothing happens.

The first thing a service technician would check is the AC power line cord that fits into the safety interlock at the rear of the set. It should be unplugged from the wall at one end and disconnected from the set at the interlock connection. The prongs on the plug that attaches to the wall receptacle should be connected (shorted) together with the jumper wire, as shown in figure 1. The test leads from an ohmmeter are placed at the other end. If the pointer deflects to zero, this indicates that the line cord is good. There is no break (open circuit) in the line cord. The ohmmeter shows that there is continuity in the circuit.

If the set has a small light bulb to indicate when the set is on, this may

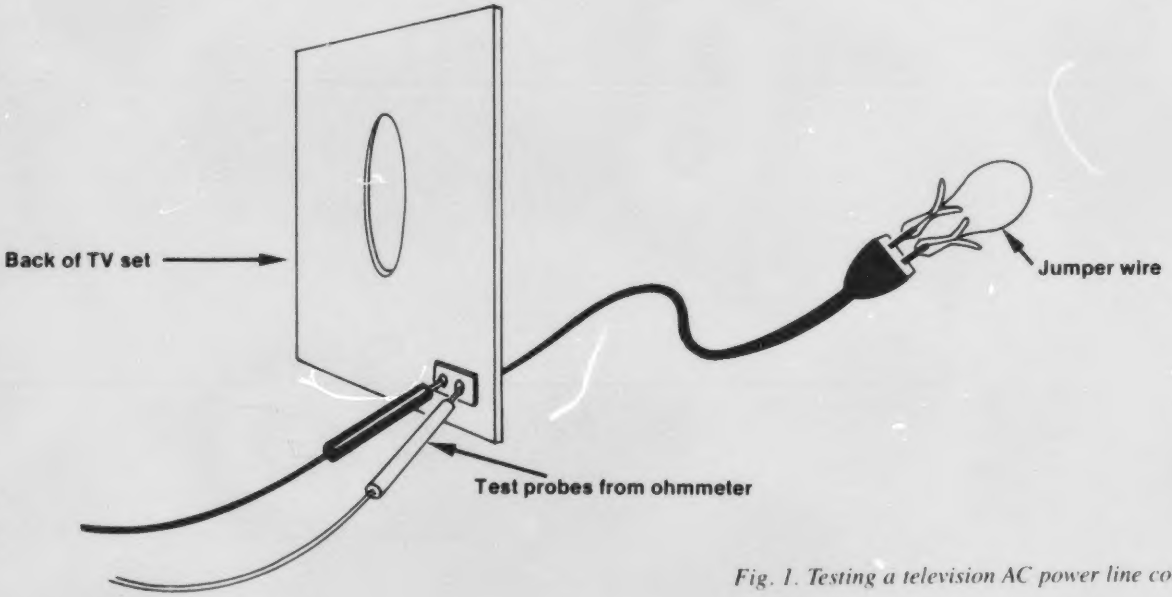


Fig. 1. Testing a television AC power line cord

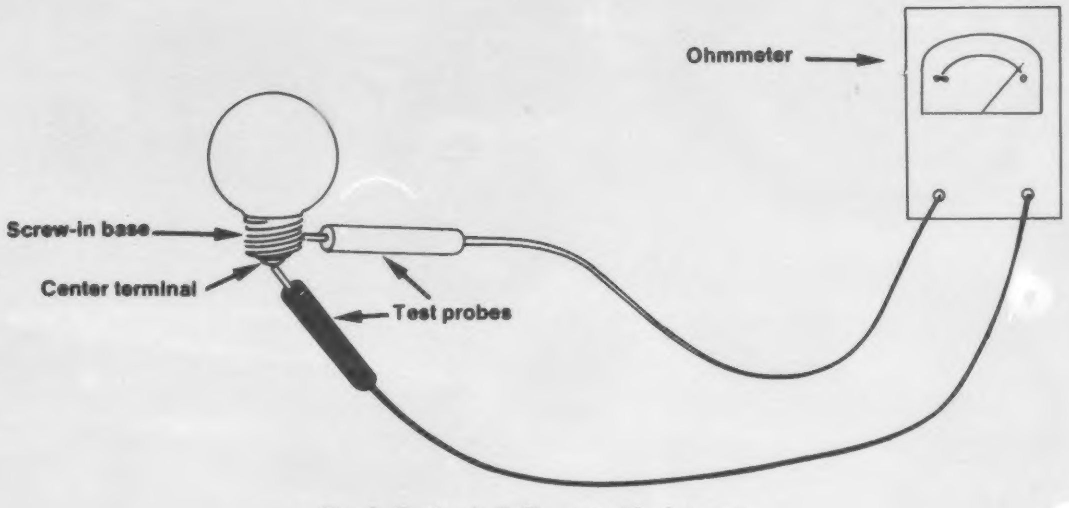


Fig. 2. Testing bulb filament with ohmmeter

also be tested, as shown in figure 2. The metal base of the bulb is connected internally to the filament. The ohmmeter test leads should be used as shown in figure 2. If the filament of the bulb is burned out, there is no continuity (pointer does not move) through it. In that case, replace the bulb. Fuses and circuit breakers can also be tested for continuity this way.

Some other possible causes of a completely dark and soundless television set are a faulty AC line switch, fuse, or circuit breaker. The ohmmeter continuity test can be used to discover the faulty component.

A burned-out resistor can also cause a lot of trouble. To check a suspected resistor, you should first desolder or cut one lead of the resistor, as shown in figure 3. The reason for this is so that the battery current from the ohmmeter will not travel through another path in the circuit, which will give you a false reading. When one lead of the resistor has been detached, an ohmmeter resistance test will detect an open circuit through the resistor. All continuity and resistance tests are made with the power to the equipment off.

Voltage Testing

The voltmeter can help solve many troubleshooting problems. It is second only to the ohmmeter in its frequency of use by service technicians. The test leads from the voltmeter must always be connected in parallel (shunt) across the component where voltage is being measured. This usually means that one test lead is connected to common

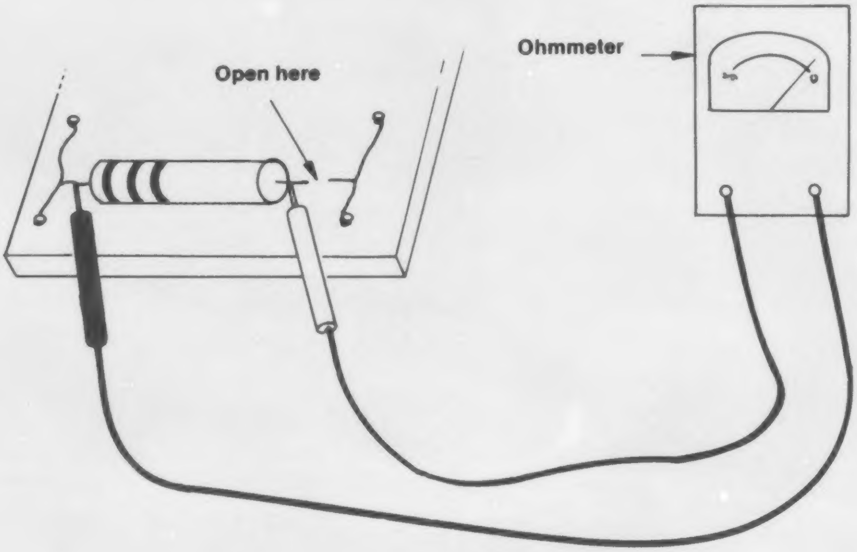


Fig. 3. Checking a resistor with an ohmmeter

ground and the other test lead is connected to a test point, as in figure 4. These test points are shown on the manufacturer's service data for all radio and television sets. The test leads should be connected to the test points before the power is turned on. These test points are usually abbreviated in schematics as TP-1, TP-2, TP-3 (see fig. 5).

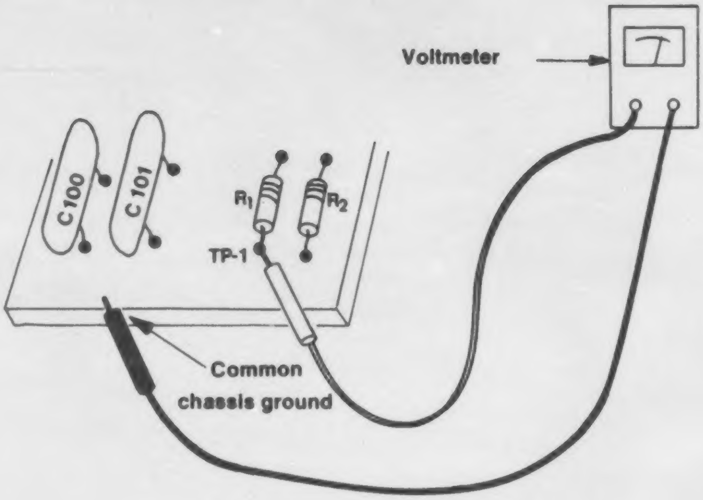


Fig. 4. Measuring voltage

Since test leads from an ammeter must be connected in series, the circuit must be cut to measure current. To avoid this time-consuming process, technicians usually measure the voltage and then use Ohm's law to compute the current. The resistance is always easy to obtain from the manufacturer's service data by reading the resistor code and actual measurements. When the voltage and resistance are known, the Ohm's law formula to find the current (I) is $I = E/R$.

In other instances, it is possible to read an ohmmeter to determine the action of current in a circuit. For example, a rough test to tell if a capacitor is operating in a circuit can be given the capacitor by using an ohmmeter. With the resistance range switch in the R × 10K position, the test leads of an ohmmeter are connected to the capacitor leads. Any capacitor should cause some initial deflection of the pointer (from full-scale reading) since the capacitor is charged by the ohmmeter battery. The pointer will indicate the actual capacitor resistance when the capacitor is fully charged. The capacitor is open if no deflection of the pointer occurs. The action of current in the circuit has been observed through the use of the ohmmeter.

The more you, as a service technician, can use your meter to remedy faulty circuits and service electronic equipment, the better a technician you will be. You can have your instructor use a pencil or some similar object as a pointer. It can be placed over the meter scales shown in figure 6. Remember that for the top ohmmeter scale and the DC scale under it, two units are represented by each of the smallest divisions. Practice reading all of the scales. Place your eyes directly over the pointer as you read so you will train yourself to read accurately.

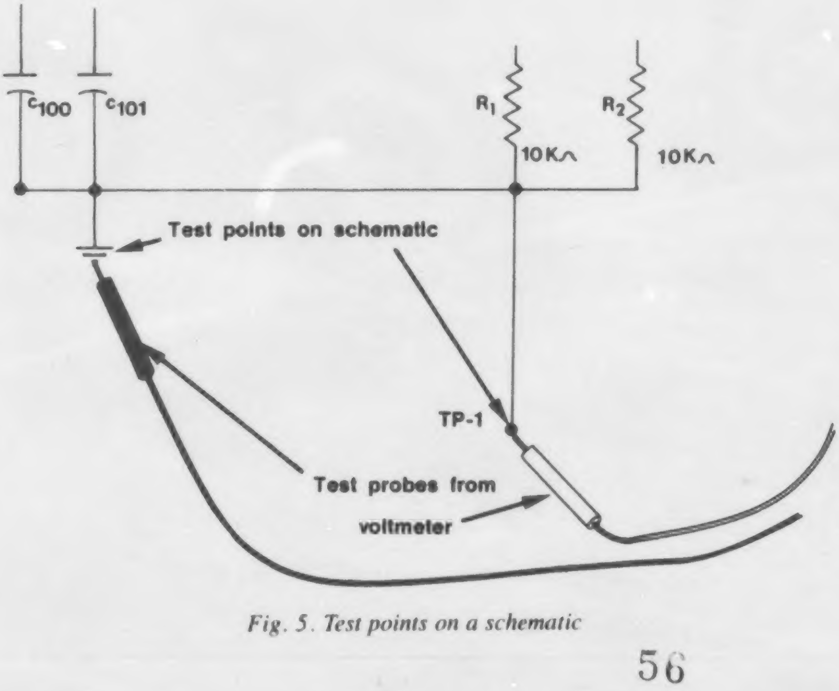


Fig. 5. Test points on a schematic

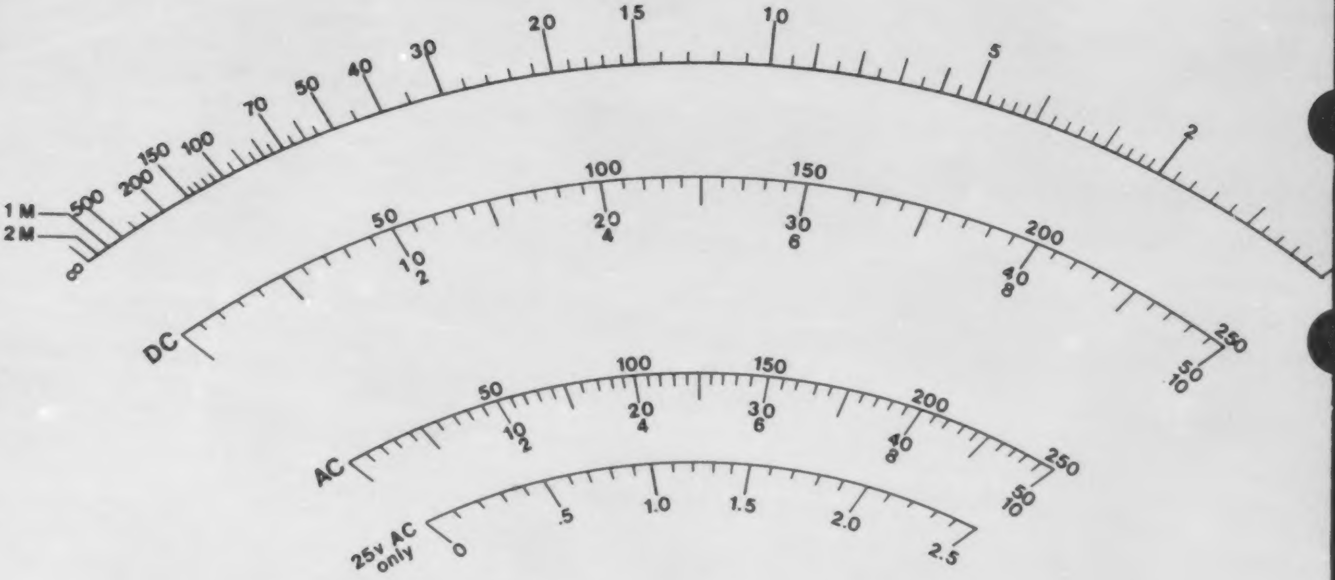

1 M
2 M
∞
500
200
150
100
70
50
40
30
20
15
10
5
2
DC
50
100
150
200
250
10
2
20
4
30
6
40
8
50
10
AC
50
100
150
200
250
10
2
20
4
30
6
40
8
50
10
25v AC only
0
.5
1.0
1.5
2.0
2.5

Fig. 6. VOM meter scales

Exercise

1. What troubleshooting procedure should be followed to check a radio or television set that developed a burning smell at the back and then suddenly went out completely?
2. What are the two most useful functions of a VOM?
3. How should a resistor in a radio or television circuit be tested?
4. How is voltage checked using the manufacturer's schematics and specifications?
5. What is the quickest way to find the current at a certain location (resistance) in a circuit?
6. How can you check the action of a capacitor without a special capacitor tester?

D-5

VOM Accessories—High-Voltage Probes and Radio-Frequency Probes

Objectives: After completing this assignment, you should be able to—

1. tell some of the special aspects of testing high-voltage circuits and
2. explain why special radio-frequency probes are used to measure high-frequency voltages.

Dangerous high voltage can appear at unexpected points in malfunctioning electronic circuits found in radio and television sets. You should be very careful when testing high-voltage circuits. Stored charges on capacitors can be lethal (deadly).

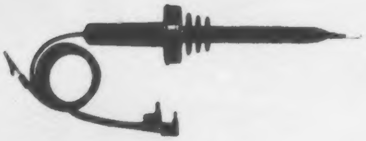


Fig. 1. High-voltage probe

High-Voltage Probes

The VOM meter range limit for most DC VOMs is 1,000 volts. A high-voltage probe, such as the one shown in figure 1, can be used to extend the range indication up to 25,000 volts. For example, when the high-voltage probe leads are plugged into the DC terminals of the VOM, the high voltage can be read on the 250-volt scale. The reading on the 250-volt scale would be multiplied by 100 to give a 25,000-volt range. A special DC high-voltage probe might be specifically made to operate on a specified voltage range for a particular VOM. High-voltage DC probes are usually not interchangeable between different types or models of VOMs. A high-voltage probe designed to be used on the 250-volt range of a particular 20,000-ohms-per-volt VOM will not measure accurately on the lower voltage ranges of a different 20,000-ohms-per-volt VOM.

To utilize the standard VOM, the high-voltage probe acts as an external multiplier resistor. This allows voltages as high as 30,000 volts to be read on the 300-volt meter scale.

A special self-contained type of high-voltage test probe is available with a built-in voltmeter, such as shown in figure 2. This test probe instrument is used by attaching the alligator clip to ground and touching the test probe tips to the high-voltage test point. The voltage is read directly from the built-in meter.

Radio-Frequency Probes

The standard AC voltage function of a VOM will not measure radio frequencies. These high frequencies are above the capacity of the meter. A special radio-frequency (RF) probe, like the one in figure 3, must be used for RF voltage measurement. A high-sensitivity VOM should be used with the RF probe for accurate measurement of RF voltages.

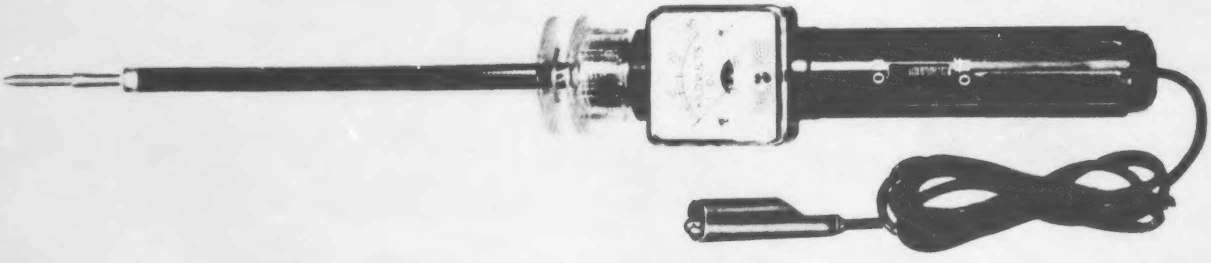


Fig. 2. High-voltage test probe with built-in meter

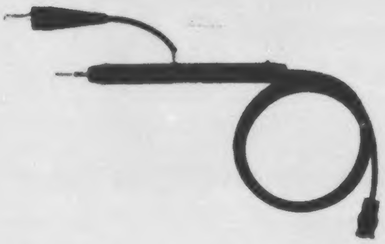


Fig. 3. High-voltage and RF probes

Exercise

1. How could testing high-voltage circuits be hazardous?
2. What is the meter range limit for most DC VOMs?
3. How does the high-voltage probe extend the range of a VOM meter?
4. How can a special self-contained high-voltage test probe be used to measure high voltage?
5. Why must high-frequency voltages be measured with radio-frequency probes?

Section

E

Vacuum Tubes and Semiconductors

E-1. Vacuum Tubes
E-2. Semiconductor Diodes
E-3. The Semiconductor Diode Rectifier
E-4. The P-N-P Transistor and N-P-N Transistor
E-5. Transistor—Physical Appearance and Identification

E-1

Vacuum Tubes

Objectives: After completing this assignment, you should be able to—

1. tell how electrons flow in a vacuum tube;
2. tell how the diode operates as a current rectifier;
3. discuss the characteristic curves of vacuum tubes; and
4. name and describe the multi-element vacuum tubes.

The English scientist J. A. Fleming designed the first practical electron tube. He called it a *valve*. This electron tube controlled the flow of electrons in much the same way as a water faucet valve controls the flow of water. There are many different types of these tubes but the most important one for the radio and television technician to understand is the vacuum tube.

A **vacuum tube** is an electron tube that has had as much air as possible removed from its outer glass envelope. Within this glass envelope, at least two metal elements are placed to control the flow of electrons in a vacuum. One element is called the *cathode*. It has a more negative potential than the other element. The second element is called the *anode* or *plate*. It has a more positive potential (voltage) than the cathode. This two-element vacuum tube is called a vacuum tube **diode**.

Thermionic Emission

The emission of electrons from a heated cathode or emitter is called *thermionic emission*. Electron emitters are classified according to the method used to heat them. They can be either directly heated or indirectly heated.

The *directly heated* cathode has a voltage source connected directly to it to cause it to heat up and emit electrons. Figure 1 shows this type of diode tube and the schematic symbol for it.

The *indirectly heated* cathode is constructed as shown in figure 2, with the addition of a special wire heater. A voltage source is connected to the heater filament. The cathode is not connected to the heater, but the heater is located so close to it that the cathode absorbs enough heat to operate as an emitter of electrons. Free electrons enter the empty space (vacuum) between the cathode and the plate. When the plate is more positive than the cathode, the free electrons will move through the vacuum to reach it. Because the positive plate attracts and collects electrons, it is also referred to as the *collector*.

Diode Rectification of Current

When an AC current is applied to a diode tube, as shown in figure 3, the output (i_p) received at the load (R_L) is a pulsating direct current. The output waveform is graphically shown in figure 3 as only the top positive half of the alternating-current cycle. The change in direction of current has been eliminated, and the output is direct current. This is called *rectification* of current.

To be of use in the power supplies of

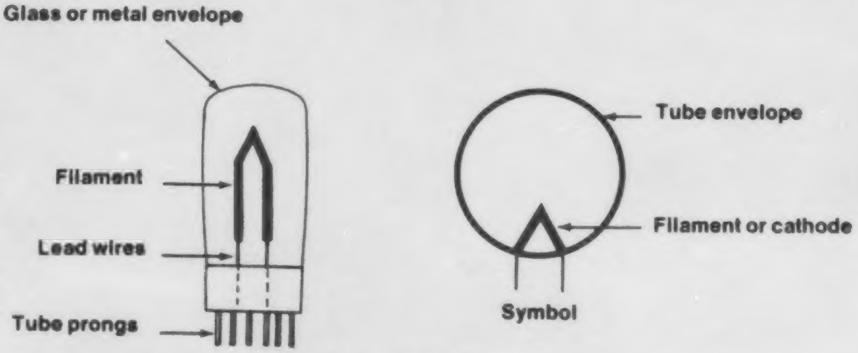


Fig. 1. Directly heated cathode

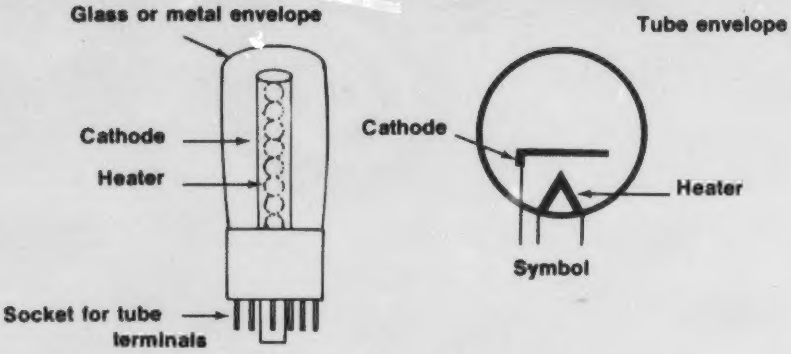


Fig. 2. Indirectly heated cathode

radio and television sets, this direct current must be filtered in stages until the waveform begins to appear as a straight line. The diode vacuum tube will only allow current to flow in one direction, from the cathode to the plate. The current cannot flow from the plate to the cathode because the electrons are repelled by the surplus of electrons at the cathode. Since the plate is operated at a higher positive potential (voltage) than the cathode voltage, the electrons will always be attracted to it. Unlike charges attract each other. Like charges repel each other.

Characteristics of Vacuum Tubes

A definite relationship exists between DC plate voltage and DC plate current in a vacuum tube. The characteristics of a vacuum tube are established by this relationship between plate voltage, plate current, and cathode temperature. The way in which these three variables affect vacuum-tube operation is best shown through the use of special graphs called *characteristic curves*.

Characteristic curves are charts of *cause* and *effect*. Two reference lines are used in these charts. A vertical line and a horizontal line serve as scales to indicate the units of volts, amperes, and ohms.

One important characteristic curve is the plate-current/plate-voltage characteristic curve shown in figure 4. In this graph, the voltage is considered to be the cause, and the current is the effect. For every increase in (DC) plate voltage, there is an increase in (DC) plate current. These increases can be plotted as points on the graph by a series of horizontal and vertical projections. In figure 4, the heavy dark line has been drawn between the various points of projection. This heavy line is the characteristic curve.

Linear and Nonlinear Characteristics

Two terms often used to describe characteristic curves are *linear* and *nonlinear*. In figure 5, the curved portion of the graph is referred to as nonlinear, while the straight line portion is referred to as linear.

Linear and nonlinear characteristics can be further divided into two other types called *static* and *dynamic*. The discussion of tube characteristics up to this point has been concerned only with static characteristics. Static characteristics do not reflect the typical operating conditions of vacuum tubes, because there is no load in the external circuit under these conditions.

Dynamic Characteristics

For any vacuum tube to operate in a normal manner, there must be a load resistor (R_L) in its external circuit, as shown in figure 6. Figure 6 shows that the diode current (I) flows outside of the tube. The output of the tube is represented as a voltage drop across the load. With the addition of a load, the operating characteristic of the tube is changed. The plate-current/plate-voltage curve now represents a dynamic characteristic.

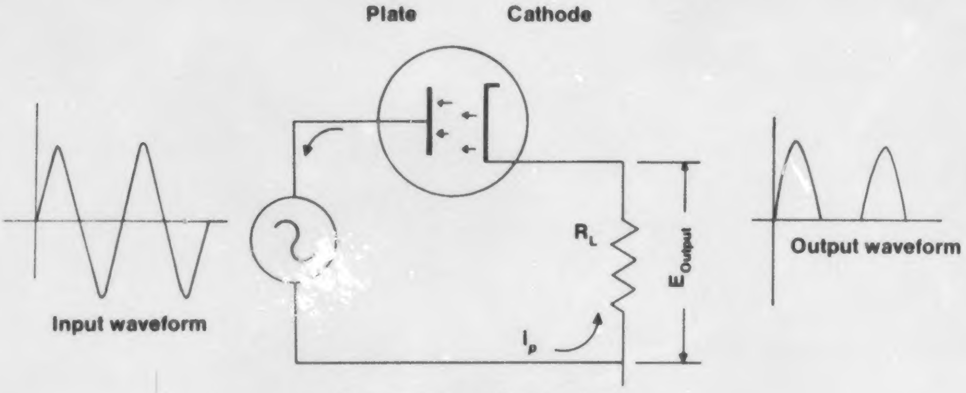


Fig. 3. Current flow in diode

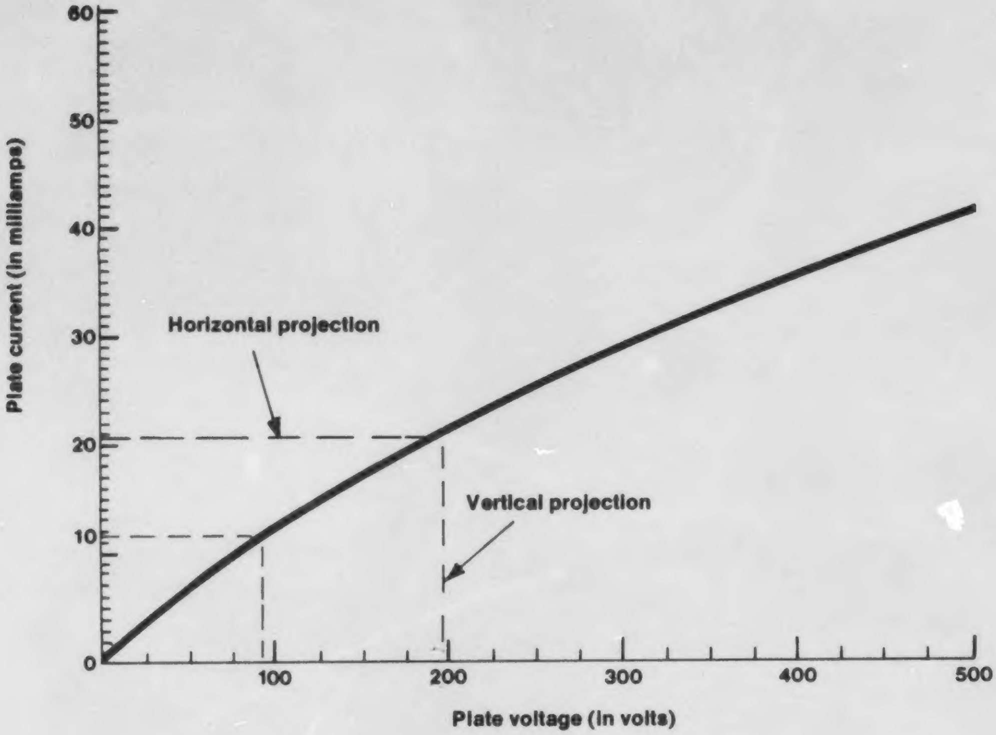


Fig. 4. Plot of characteristic curve

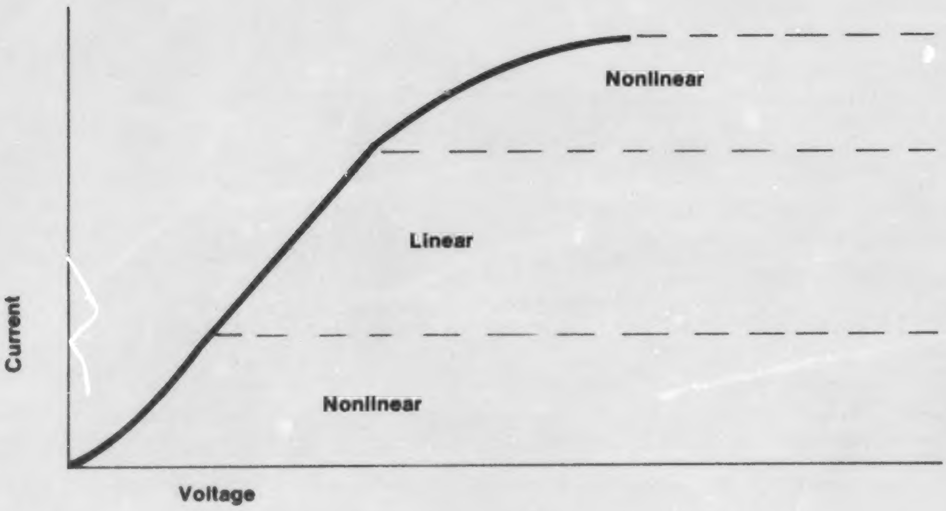


Fig. 5. Linear and nonlinear curves

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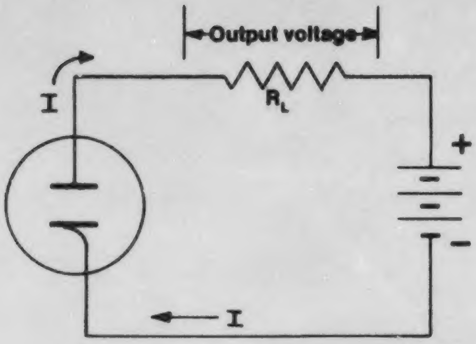


Fig. 6. Diode circuit with load resistor

Triode Vacuum Tubes

In 1907, Lee De Forest added a third element to the diode tube. This **triode** vacuum tube made it possible to amplify sound waves and made radio communication a reality. In the triode, the cathode and the plate perform the same functions as before. The third element, called the *control grid*, is placed between the cathode and the plate. Figure 7 shows the arrangement of the cathode, the control grid, and the plate in the triode.

The control grid assembly usually has a helical form and consists of many turns of fine wire wound in a sort of screenlike structure. The control grid controls the amount of electron flow through the tube. The control grid is operated at a negative potential. It can be placed at such a high negative potential that it will cut off the flow of current through the tube. This is called the *cutoff voltage*. The grid has more control over plate current than does the plate voltage. This control of plate current is very important in electronic circuits found in radio and television sets. The same principle involved here regarding the control of current flow and amplification will be examined in a later assignment on transistor operation.

The triode symbols used in schematic drawings of electronic circuits are shown in figure 8. The symbol used to represent the grid is a dashed line. The radio and television technician must be able to identify every component used in the electronic circuits by reading these schematic drawings.

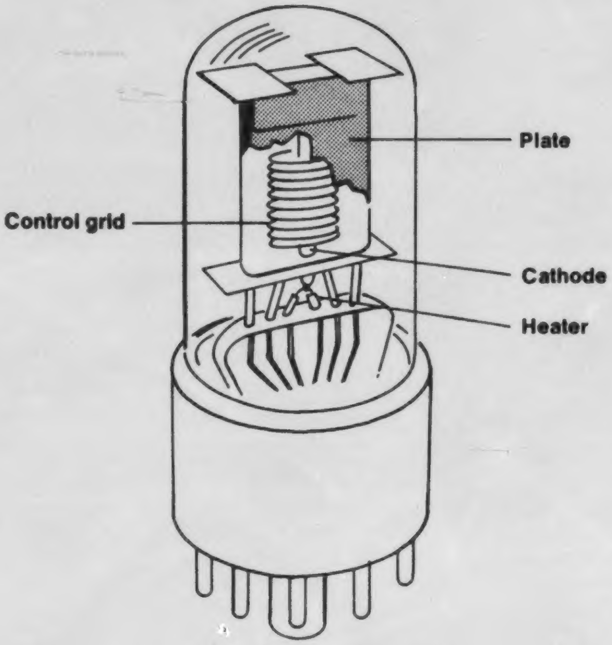
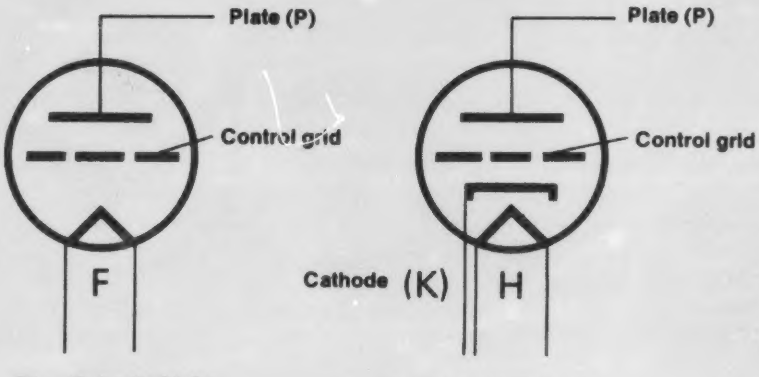


Fig. 7. Triode vacuum tube



Directly heated tube

Indirectly heated tube

Fig. 8. Triode symbols

Tetrodes and Pentodes

It was soon discovered that triodes did not work well at high frequencies. To meet this need, **tetrode** and **pentode** vacuum-tube amplifiers were produced.

The tetrode has a fourth element, called a *screen grid*, placed between the control grid and the plate. The screen grid operates at a positive potential. It has more effect on plate current than does plate voltage because of its shielding effect. The high frequency is no problem for the tetrode, but the tetrode does not have a linear operation characteristic. This causes distortion (audio or video waveforms not reproduced properly) in the output when a large input waveform (signal) is applied to the tube. Tetrode amplifiers have limited use for this reason.

With the addition of a fifth element called a *suppressor grid*, the pentode tube solves the problem of distortion found in tetrodes. Figure 9 shows the construction of a pentode tube and the arrangement of all of the elements that have been discussed. Figure 10 shows the schematic symbol for the pentode.

Many types of multi-unit tubes will be found in older radio and television sets. Radio and television service technicians still repair these vacuum-tube-operated radio and television sets. Figure 11 shows other symbols used for multi-element vacuum tubes. In these vacuum-tube circuits, about 80 percent of the repairs involve replacement of the tubes.

A valuable aid to the service technician is a *receiving tube manual*. These manuals give tube characteristics and other important technical data for most electron tubes. These manuals can be purchased at radio and television electronic supply houses.

Most service technicians check to

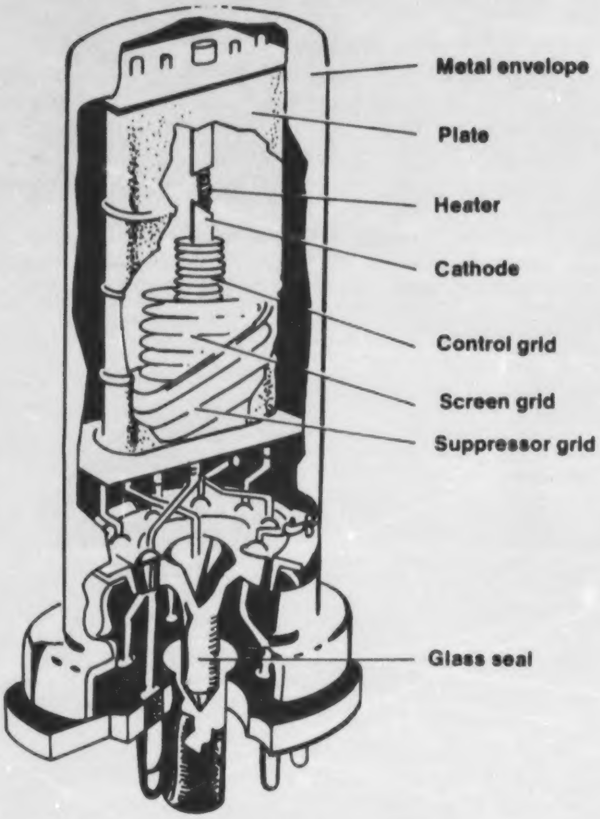

Metal envelope
Plate
Heater
Cathode
Control grid
Screen grid
Suppressor grid
Glass seal

Fig. 9. Pentode vacuum tube

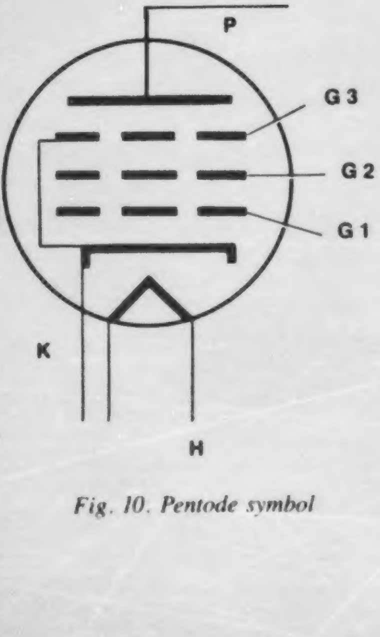


Fig. 10. Pentode symbol

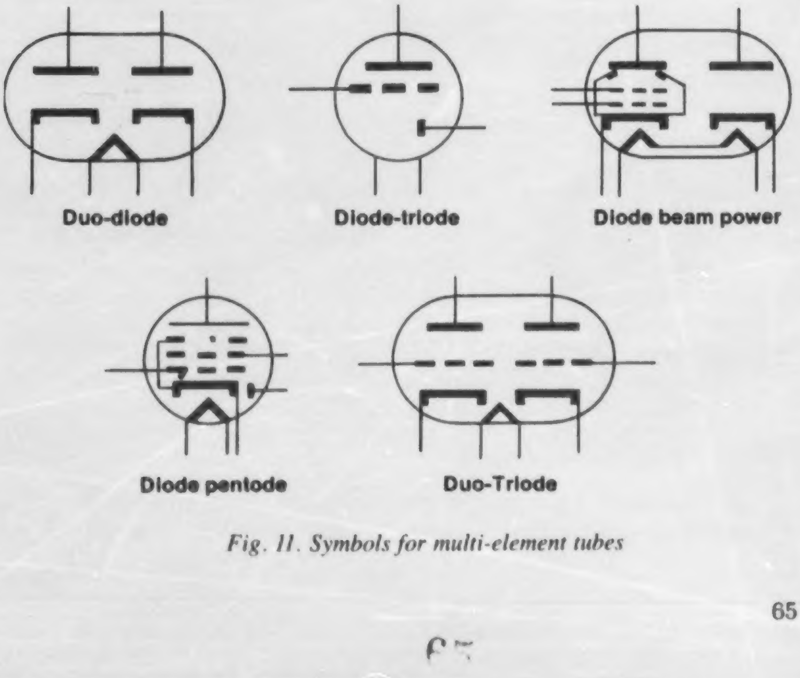

Duo-diode
Diode-triode
Diode beam power
Diode pentode
Duo-Triode

Fig. 11. Symbols for multi-element tubes

see if a tube is faulty by using a new tube as a direct replacement into the questionable circuit. There are many *tube testers* on the market. Most of them do not test the tube under exact circuit conditions and are of little value compared to a replacement tube.

Exercise

1. What is thermionic emission?
2. What are the two methods of heating cathodes?
3. How is a diode vacuum tube constructed?
4. What is a rectifier?
5. How does a vacuum tube operate as a current rectifier?
5. What are vacuum tube characteristic curves?
7. How do the multi-element (triode, tetrode, pentode) tubes operate?

66

E-2

Semiconductor Diodes

Objectives: After completing this assignment, you should be able to—

1. tell how semiconductor diodes have been produced and used in electronic circuits;
2. discuss N-type semiconductors;
3. tell how P-type semiconductors are different from N-type semiconductors; and
4. explain how the junction barrier affects the operation of the junction diode.

All materials may be considered to fall into one of three general categories. They may be classified as conductors, insulators, or semiconductors. You have learned about conductors and insulators in previous assignments. In this assignment you will learn about *semiconductors*.

Semiconductors

A semiconductor is neither a good conductor nor a good insulator. It is the general term used to include all materials falling between insulators and conductors regarding the ability to conduct current. Semiconductors have a range of resistance that falls between that of insulators and that of conductors, as shown in figure 1.

Semiconductors can be made very small and lightweight. They require no filaments or heaters, as vacuum tubes do, and they consume very little power. In the electronic circuits of modern radio and television sets, semiconductors have almost completely replaced vacuum tubes. The only exception to this is the cathode-ray picture tube used in television sets. Eventually the cathode-ray tube will be a semiconductor device.

Semiconductor Crystal Structure

Semiconductor materials such as silicon, selenium, and germanium are used to make semiconductor diodes and transistors. These materials have a crystal structure that is called a *lattice*. A crystal lattice structure for silicon atoms is shown in figure 2. Only the outer orbit of these atoms is shown. There are four outer electrons orbiting around the nucleus of each silicon atom. Notice how the pair bonds are formed by these outer electrons. This gives each atom the effect of sharing electrons with the adjoining atoms. The atoms are balanced, because each nucleus contains the same amount of protons as there are electrons orbiting around it. In a pure semiconductor material, most of the atoms are balanced and there are few free electrons. In this form, the material is not useful for diodes or transistors.

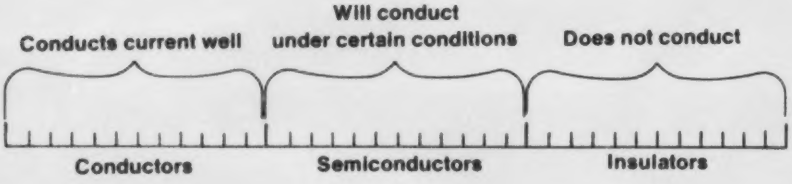


Fig. 1. Relationship of conductors, semiconductors, and insulators

N-Type Semiconductor

By adding an impurity substance to the semiconductor crystal structure, the resistance is lowered. This makes semiconductors useful in all applications that vacuum tubes were formerly used.

An N-type crystal (see fig. 3) can be produced by adding an impurity such as antimony or arsenic. Since the blending of the impurity with the pure semiconductor adds a free electron to each atom, it is called a *donor*. When impurities are added to the pure semiconductor, this is called *doping*.

Silicon and germanium crystals have four electrons in the outer orbit of each atom (see fig. 2). Antimony and arsenic are "pentavalent" materials. This means that they have *five electrons* in the outer orbit of each of their atoms. When one of these donor impurities is added to the pure semiconductor crystals, a free electron is left over in the crystal structure. These free electrons act as carriers of electric current. In an N-type semiconductor, the major carriers of current are electrons.

P-Type Semiconductor

The P-type semiconductor has been called a P-type because *positive* charges

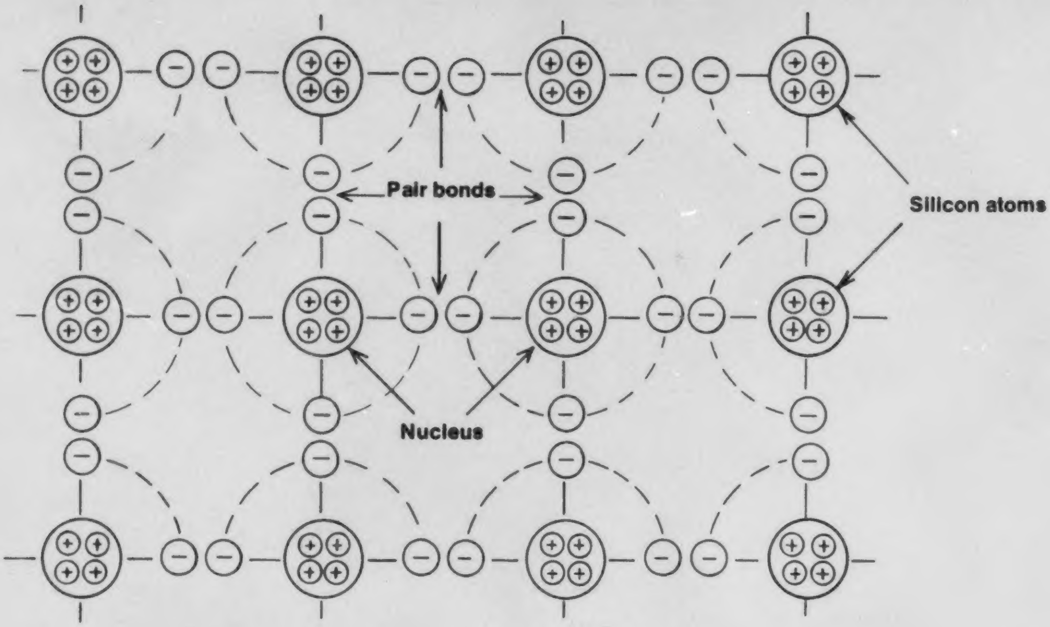

Pair bonds
Silicon atoms
Nucleus

Fig. 2. Semiconductor crystal structure

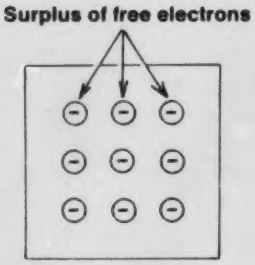

Surplus of free electrons

Fig. 3. N-Type crystal

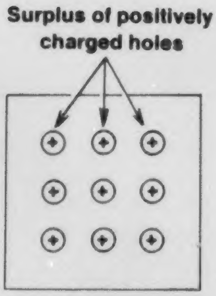

Surplus of positively
charged holes

Fig. 4. P-type crystal

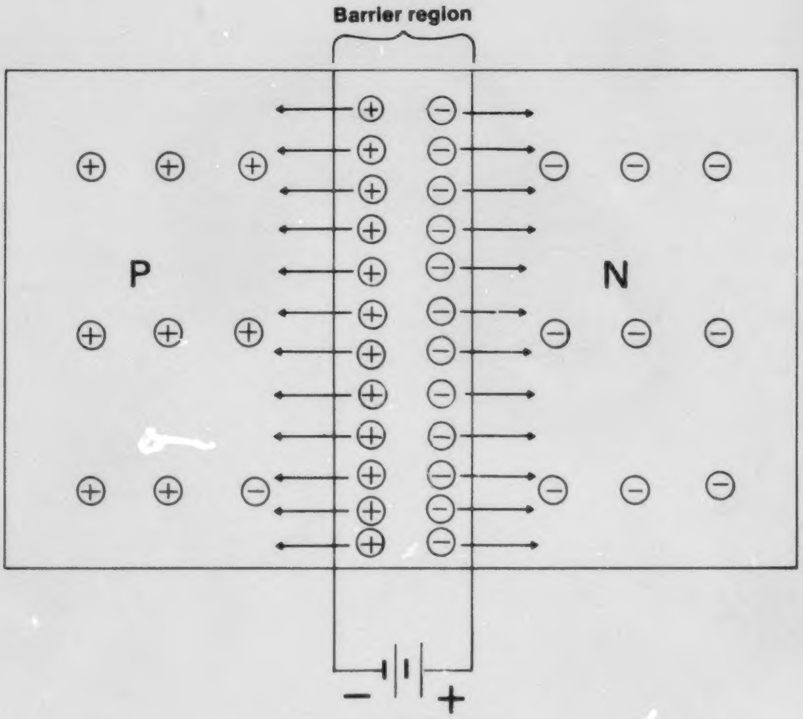

Barrier region
P
N
−
+

Fig. 5. P-N junction diode

act as the major carriers of current. When a trivalent (has three electrons in the outer orbit) impurity such as indium is added to a pure semiconductor crystal, the crystal is minus one electron. To fill this vacancy in the crystal lattice structure, an electron is borrowed from another atom. This borrowed atom fills the *hole* in the indium atom. When the conduction of current is brought about in the crystal structure, the electrons tend to move in one direction, while the holes left by them move in the opposite direction. The trivalent indium impurity has acted as an *acceptor* of electrons.

The P-type crystal has a surplus of *positively charged holes* to act as current carriers (see fig. 4). Both the P-type crystal and the N-type crystal have the effect of being neutral until an external voltage is connected to cause the conduction of current.

The Junction Diode

If a pure silicon crystal has one section doped with a trivalent impurity and another section doped with a pentavalent impurity, a junction is formed between the two sections. This is the process that is used by the electronics industry to produce a *junction diode*.

A P-type junction diode is shown in figure 5. The barrier region is formed because of a reaction between the N-type crystal and the P-type crystal. This reaction is as though a small DC battery were connected, as shown in figure 5. The holes and electrons in the barrier region are repelled away from the junction barrier. The barrier must be eliminated before current can flow through the diode.

When the P-N junction barrier is overcome by some method, the P-N junction diode becomes a rectifier of current. It is used by the electronics industry to change a ready supply of alternating current into direct current without having to use storage batteries.

Exercise

1. What is a semiconductor?
2. What are three semiconductor materials?
3. How are N-type crystals made?
4. How are P-type crystals made?
5. When an N-type crystal is joined to a P-type crystal, what effect does the P-N junction have upon the entire diode?

E-3

The Semiconductor Diode Rectifier

Objectives: After completing this assignment, you should be able to—

1. tell how the semiconductor diode can be used to rectify current;
2. compare the semiconductor diode to the vacuum tube diode; and
3. discuss forward bias and reverse bias of a semiconductor diode.

The semiconductor diode can also be used to rectify current as the diode vacuum tube has been used. The P-type crystal will readily accept electrons because it is positively charged. This crystal corresponds to the plate of a diode vacuum tube. The N-type crystal corresponds to the cathode of a diode tube because it has an available surplus of free electrons. Figure 1 shows the semiconductor diode. Figure 2 shows the circuit symbol for it.

If a battery is connected to the leads of the semiconductor diode, as shown in figure 3, the resistance is low through the diode. Current flows through the diode easily because of the abundance of positively charged holes in the P-

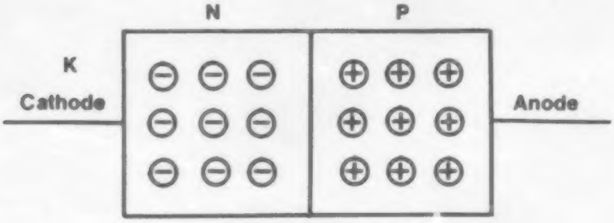


Fig. 1. A semiconductor diode

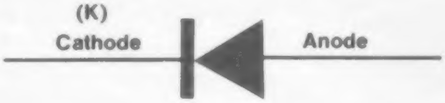


Fig. 2. Symbol for semiconductor diode

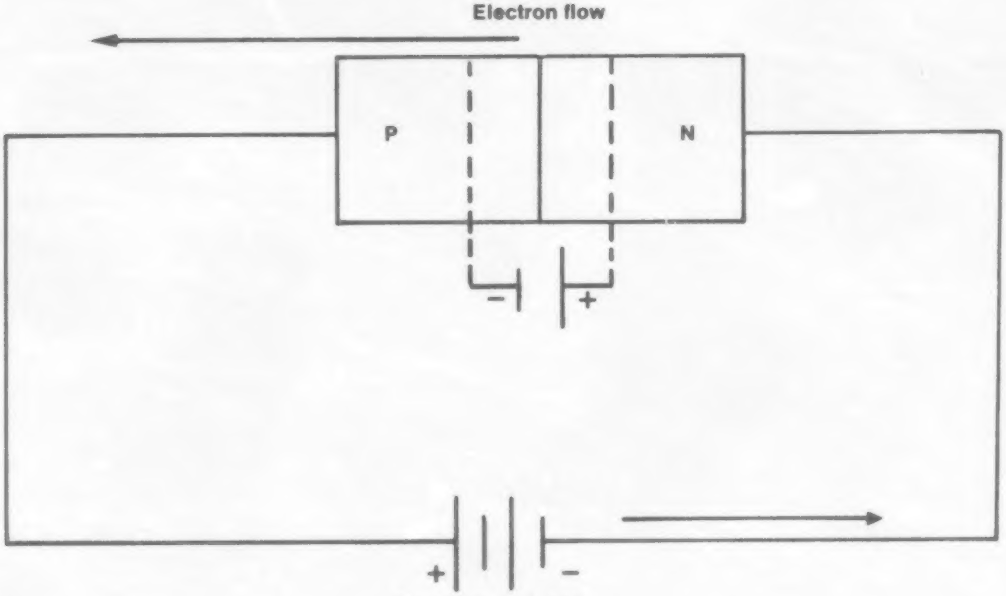


Fig. 3. Forward bias

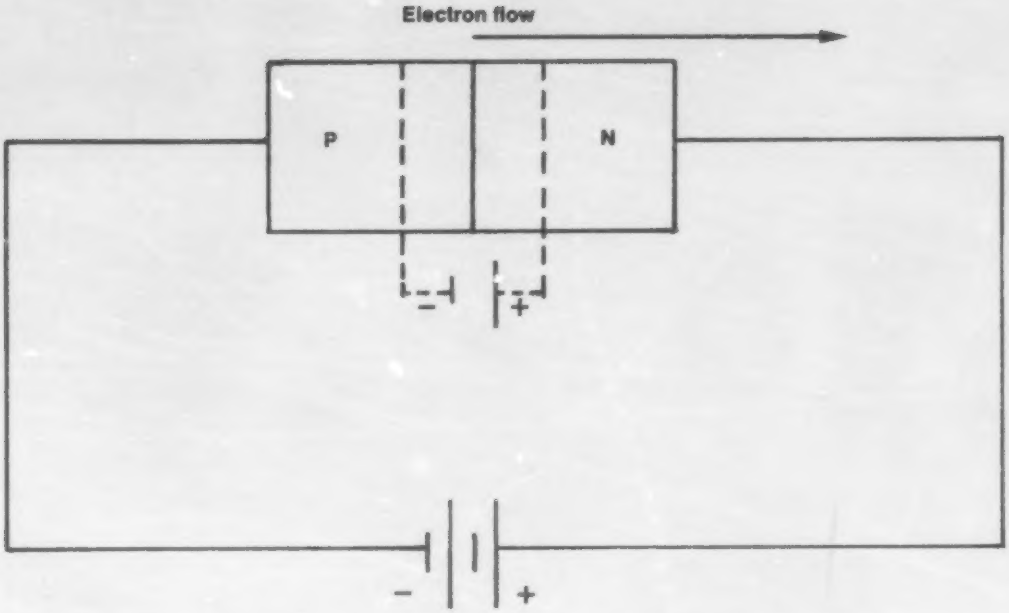


Fig. 4. Reverse bias

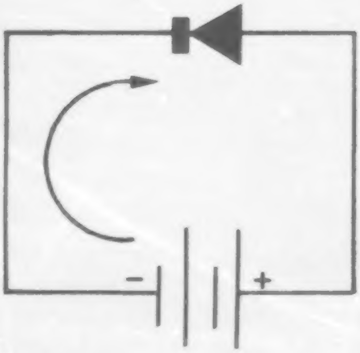


Fig. 5. Symbol for forward bias

type crystal. This is called *forward bias*. When a semiconductor diode is given a forward bias, current is able to overcome the junction barrier because of the abundance of positive holes in the P-type crystal.

When a battery is connected in the reverse direction, as in figure 4, current cannot pass through the diode. There is a high resistance through the semiconductor diode because of the abundance of electrons in the N-type crystal. Current is unable to overcome the junction barrier because the external battery is connected in the same direction as the equivalent battery circuit of the junction barrier. This only worsens the situation at the junction barrier. When a semiconductor has the negative terminal of a voltage source connected to the P-type crystal and the positive terminal connected to the N-type crystal, it has been given a *reverse bias*.

When the circuit symbol for a semiconductor diode is used, as shown in figure 5, current will always flow in the direction shown, from cathode to anode. When a reverse-bias symbol is used, as shown in figure 6, a high resistance is met and current does not flow.

The semiconductor diode is widely used in the power supplies of radio and television sets to change the standard AC house current to a pulsating direct

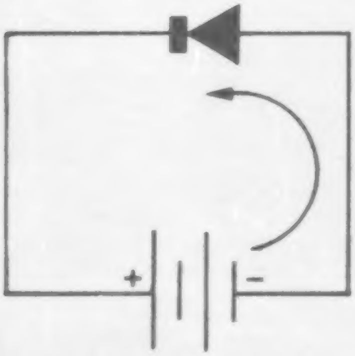


Fig. 6. Symbol for reverse bias

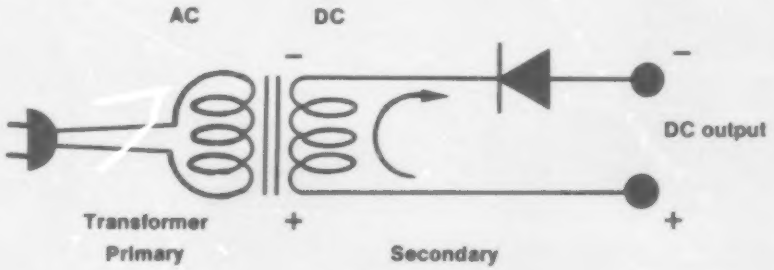


Fig. 7. Forward-biased diode conducts current.

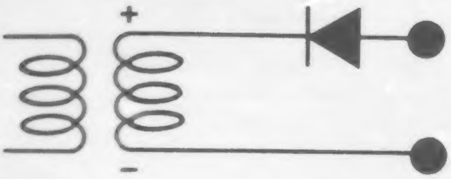


Fig. 8. Reverse-biased diode does not conduct current.

current. In figure 7, when the power transformer is plugged into an AC wall outlet, alternating current flows in the primary circuit. During the first half cycle, a negative voltage is applied to the semiconductor diode. Since the diode is forward-biased, a large current will flow. During the second half cycle, when the voltage applied to the diode changes to a positive voltage, only a very small amount of current is allowed to flow (see fig. 8).

It is easy to remember that, in semiconductor diode rectifier circuit diagrams, current always flows against the arrow from cathode to anode. The arrow diode symbol is often placed on rectifiers to show the direction the current will flow. For example, see figure 9. The direction of current flow would be from the bottom screw-in terminal, up through the silicon rectifier, and out through the top solder terminal. The bridge rectifiers shown in figure 10 are marked negative and positive to show the direction of the rectified direct current. They do not use the arrow symbol.

Exercise

1. How does a semiconductor diode rectify current?
2. How is a semiconductor diode given a forward bias?
3. How is a semiconductor diode given a reverse bias?
4. What are the similarities between the two elements of a vacuum tube diode and the elements of a semiconductor?
5. How can you tell in which direction the current will flow in a semiconductor diode by looking at the circuit symbol for it?

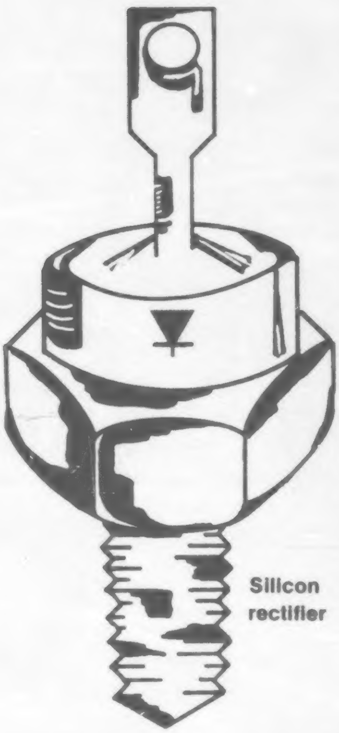


Fig. 9. The arrow shows the direction the current will flow.

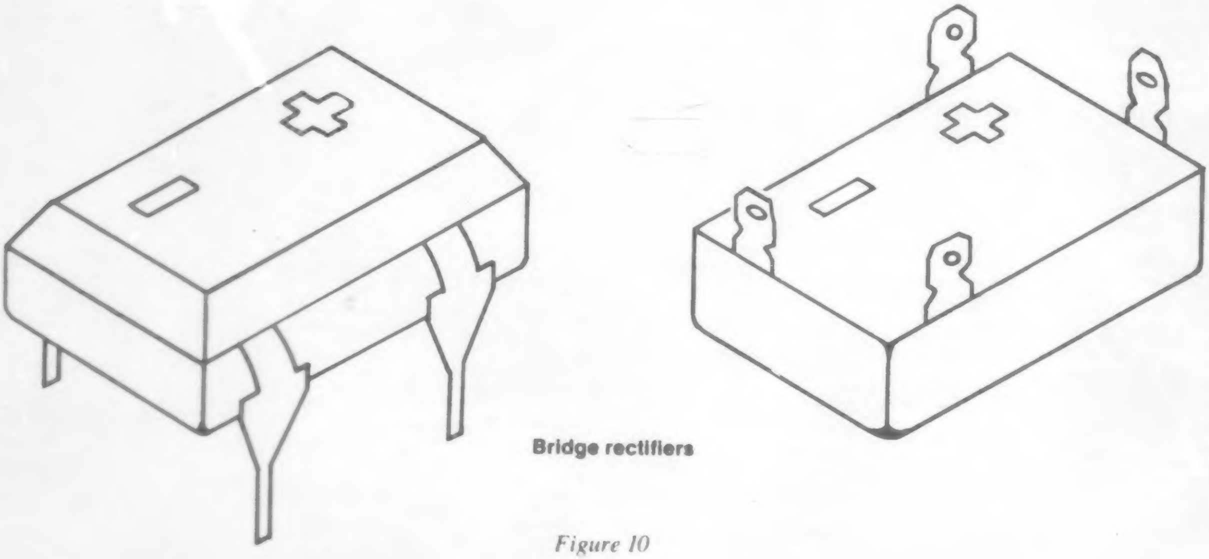


Figure 10

Objectives: After completing this assignment, you should be able to—

1. discuss the P-N-P transistor and draw the symbol for it;
2. draw the symbol for the N-P-N transistor and compare it to the P-N-P transistor;
3. tell how proper grounding is accomplished for transistor circuits; and
4. discuss the transistor as an amplifying device.

E-4

The P-N-P Transistor and N-P-N Transistor

The external action of the transistor is very similar to the action of a vacuum tube in an electronic circuit. Some advantages of the transistor over the vacuum tube are its small size, operation without a heater power supply, and operation with very little power consumption.

Transistor Types

The two basic types of transistors are the P-N-P transistor and the N-P-N transistor. These are shown in figure 1 with their schematic symbols. The **P-N-P transistor** has a very thin layer of N-type semiconductor crystal placed between two thicker P-type crystals. The **N-P-N transistor** has just the opposite arrangement. It has a thin layer of P-type crystal sandwiched between two thicker N-type crystals. This thin layer is called the *base*. One of the other two layers is designated as the *emitter*. The remaining layer of semiconductor crystal is the *collector*.

Since 1948, when it was invented at Bell Telephone Laboratories, the transistor has been used primarily as a current *amplifying device*. An amplifying device operates like a variable resistor in electronic circuits. Transistors are natural amplifying devices because the ohmic value of their solid-state material can be changed by an AC signal. This is not the case with the ordinary type of variable resistor.

Circuit Applications

By studying the simple circuitry shown in figure 2, you will learn how proper grounding is an important factor in transistor or vacuum tube circuits. When switches S_1, S_2, S_3, S_4, and S_5 are closed, the light bulbs A, B, C, D, and E will light up because the current from the power supply will flow as shown. In figure 2, each bulb has its own complete wiring. Notice that, in figure 3, a *common conductor* has been used. A lot of wire has been

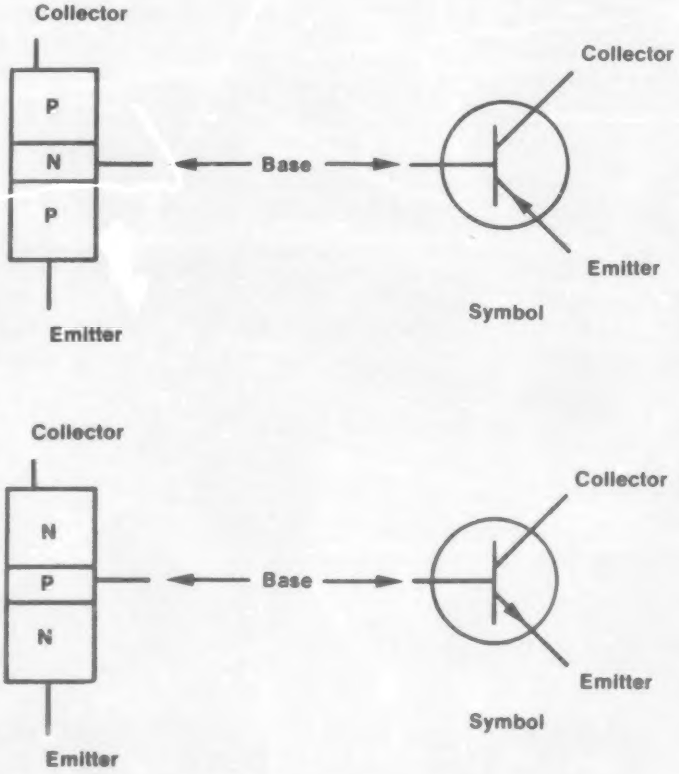


Fig. 1. P-N-P and N-P-N transistors

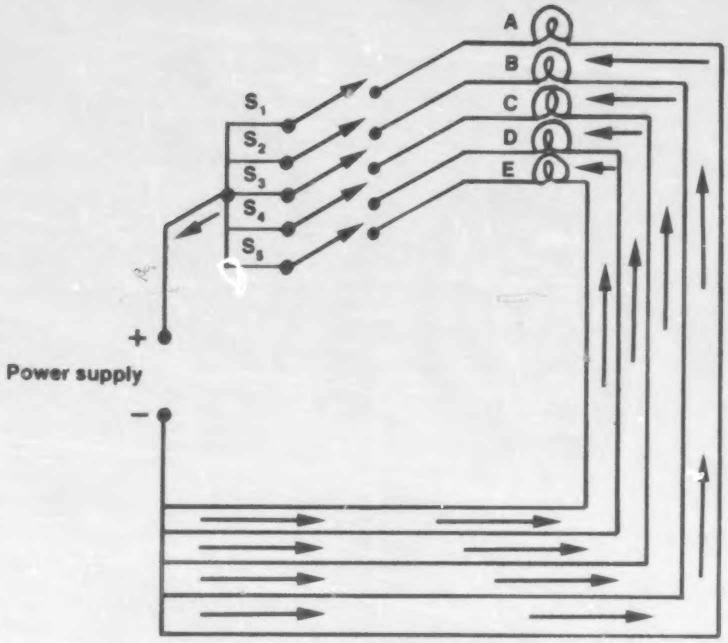


Fig. 2. Lighting circuit

saved by cutting out the five independent wires going to the negative terminal of the power supply.

Most electronic circuits are built on a metal chassis. Some of the wiring is connected directly to the chassis. This is called *grounding*. The common conductor in figure 3 has been grounded. No current flows from the circuit to ground, so in this particular circuit there is no real need for the ground. If this were a transistor amplifier circuit, the ground wire would be quite useful for its shielding action. Unwanted voltages that have been amplified (made larger after they have passed through the amplifier) may be so strong that they are heard from the speaker of a radio or television set.

A widely used method of common grounding is shown in figure 4. Here, the ground symbols signify that those particular wire leads are connected to the metal chassis.

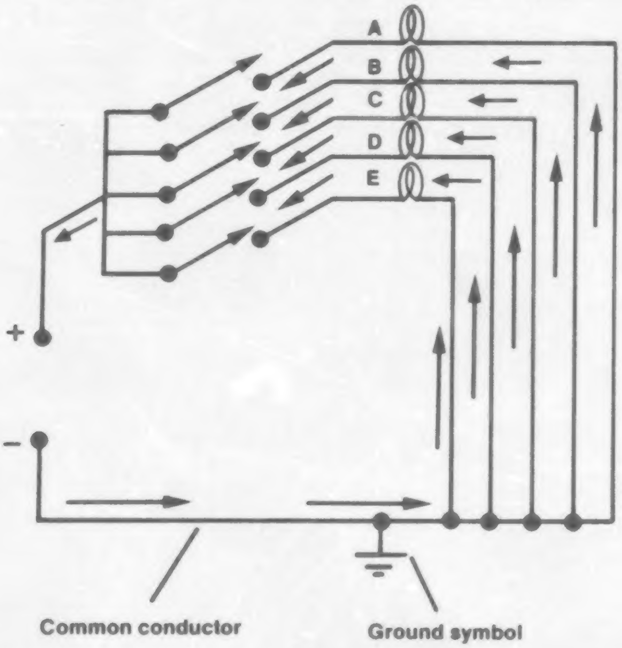


Fig. 3. Use of a common conductor

Transistor Theory

Transistor action can amplify voltage, but the way voltage is varied in a circuit is by current control. The resistance or resistivity is what we are concerned with when we think of resistors. The conductance or conductivity is the important thing with transistors. Remember that transistor action is similar to the action of a variable resistor. Figure 5 shows a series voltage regulator circuit. By sliding the variable resistor (R,) one direction or the other, the resistance can be changed. Thus, voltage and/or current is also changed. When the DC input voltage increases, the resistance of R, needs to be manually increased to maintain a constant voltage at the output. If the input voltage decreases, the resistance of R, must be decreased.

Changes in the load resistor can also come about with age and changing circuit conditions. The series regulator can compensate for changes in the load. R, and the load resistor have formed a voltage divider network. This divides the total input DC voltage proportionately. To maintain the same proportion when the load resistor decreases in value, R, must also be decreased in value. When the load resistor increases in value, R, must also be increased. A variable resistor is ordinarily not used for such voltage regulator circuits. A special type of semiconductor device called a *zener diode* is often used because it is an automatic regulator. A variable resistor cannot ordinarily be used, because the voltage changes occur too rapidly to be corrected manually.

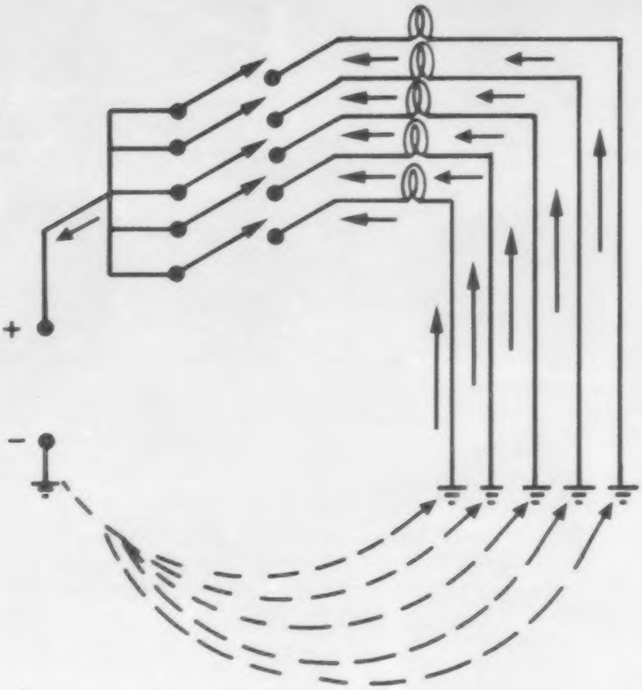


Fig. 4. Use of a common ground

Transistor Action

If the variable resistance R_v (see fig. 5) is increased, the voltage across R_v increases and the current through R_v decreases. Transistor action works basically the same way in the circuit shown in figure 6. An N-P-N transistor is substituted for the variable resistor in the previous circuit (fig. 5). By looking at the transistor symbol in figure 6, you could tell that it was an N-P-N transistor, even if it were not labeled, by using this memory device. When the arrow is *N*ot *P*ointing i*N* towards the base, it is an N-P-N transistor. When the arrow of the emitter points to the base, of course, it is a P-N-P transistor. Remember that current will flow against the arrow in the external circuit regardless of whether the transistor is an N-P-N transistor or a P-N-P transistor.

In the circuit in figure 6, as the conductivity of the transistor increases, its resistance decreases and its voltage decreases. The electrical variation that the transistor reacts to is sent to the

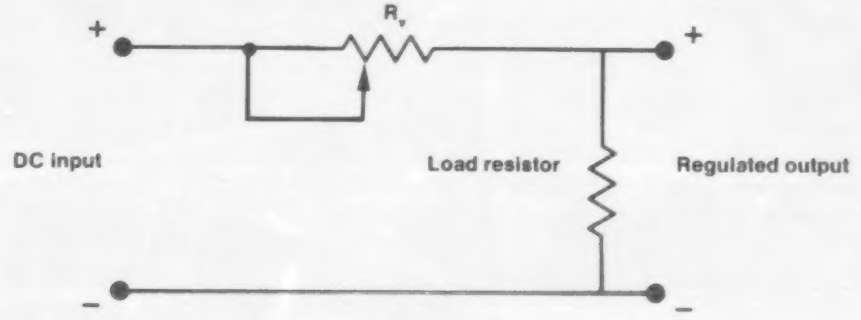


Fig. 5. Voltage regulator

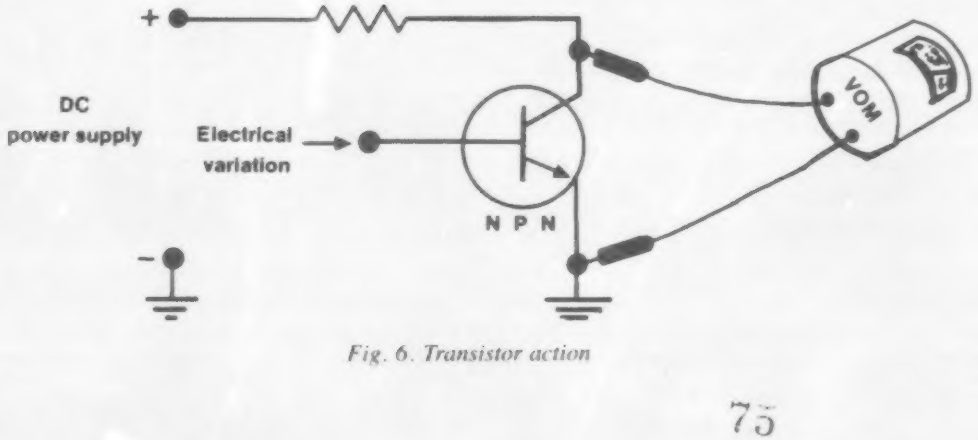


Fig. 6. Transistor action

base through the protruding base lead. A positive power supply is connected to the collector because it is an N-P-N transistor. In the case of a P-N-P transistor, a negative power supply would be used to assure proper operation. The voltage variations can always be measured across the emitter and collector terminals.

Differences between N-P-N and P-N-P Transistors

Some literature that you might read on solid-state (semiconductors) electronics will use the conventional flow theory. This is the old Ben Franklin idea that current flows from positive to negative. When this happens, you must remember to reverse your thinking from the electron flow theory of transistor action.

Both N-P-N and P-N-P transistors can be used for the same electronic purposes by biasing them in different ways. They are equivalent in the task they perform but opposite in the way they perform it. The main current or working current is through the transistor from emitter to collector in the N-P-N transistor. Electrons are the major carriers of current both inside the transistor and in the external circuit. However, in the case of the P-N-P transistor, holes (positive polarity) are the major current carriers through the transistor while electrons flow in the external circuit. The working current from emitter to collector in the P-N-P transistor is in the direction of the emitter arrow, like the conventional flow theory. This is opposite to the action inside the N-P-N transistor where the current flows against the emitter arrow in the usual manner. The emitter is used as a reference point. For current to flow in the desired direction through the transistor from emitter to collector, the proper-bias DC voltages must be present. The N-P-N transistor must have a *more positive* voltage at the base than at the emitter. The voltage at the collector must be still more positive than the base. The P-N-P transistor must have a *more negative* voltage at the base than at the emitter. The voltage at the collector must be at a higher *negative* potential than the base.

N-P-N transistors are more widely used than P-N-P transistors for several reasons. N-P-N transistors are less expensive. They operate with more speed. And they turn on and off more quickly.

Exercise

1. What symbol is used for a P-N-P transistor?
2. How is the P-N-P transistor constructed?
3. How is the P-N-P transistor different from the N-P-N transistor?
4. What symbol is used for an N-P-N transistor?
5. What two methods of grounding can be used to provide a shielding action for a transistor amplifier circuit?
6. Why does the transistor make an excellent amplifying device?
7. Why is shielding advisable in a transistor amplifier circuit?
8. What is the basic transistor action that brings about amplification through the transistor circuit?

Objectives: After completing this assignment, you should be able to—

1. compare the transistor to the triode vacuum tube;
2. describe three methods used by transistor manufacturers to identify which leads go to the emitter, base, and collector;
3. explain the importance of having available the latest manufacturer's data sheets before you service or troubleshoot transistor circuits; and
4. name five other helpful tools that can assist the service technician.

E-5

Transistor—Physical Appearance and Identification

The radio and television service technician must be familiar with the physical appearance and operating characteristics of electronic components in the equipment he or she services.

You have learned that transistors are much smaller in size and are constructed much differently than vacuum tubes. However, you should remember that *the basic function* of transistors and vacuum tubes *is the same*. In figure 1, the physical construction of a triode vacuum tube is compared to that of the transistor. The base of a transistor serves the same purpose as the control grid of a vacuum tube. The electrical variation or signal is introduced into the base of a transistor as it would be into the control grid of the vacuum tube. In general, the emitter can be compared to the cathode, and the collector compared to the plate or anode of the vacuum tube.

One difference in the physical de-

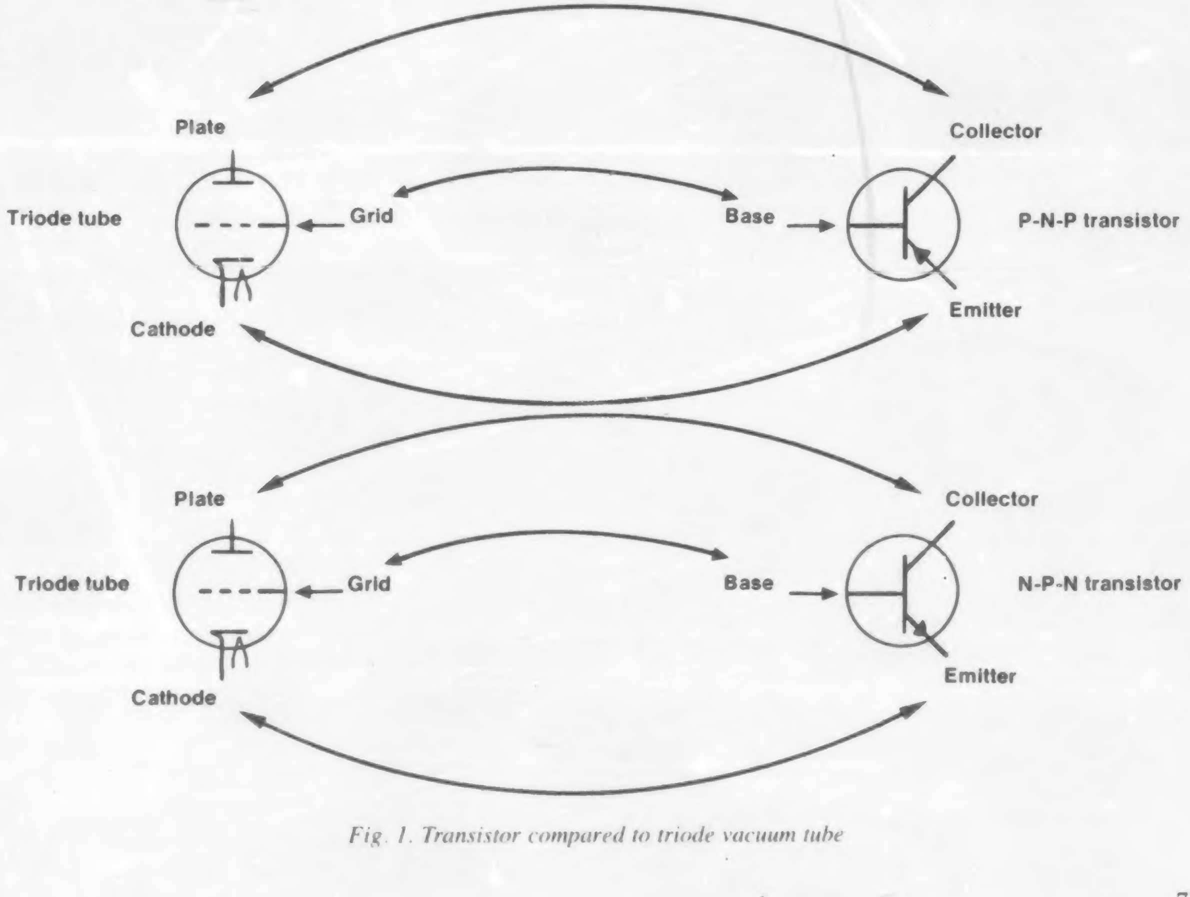


Fig. 1. Transistor compared to triode vacuum tube

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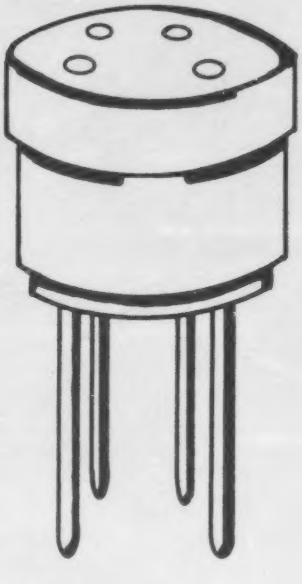

Fig. 2. Transistor chassis-mount socket

sign of transistors as compared to vacuum tubes is the method of attaching them into electronic circuits. Many transistors are not made to fit into chassis-mount sockets, as shown in figure 2, but are soldered into place. This makes it harder to replace a faulty transistor than it is to replace a faulty vacuum tube. All vacuum tubes were designed to fit into special tube sockets.

The power transistor (see fig. 3) has been designed so that the emitter and base pins or leads will fit into sockets. There is no collector lead because the collector has contact with the metal case. This terminal is the case itself which attaches to the chassis.

Transistor Lead Identification

Figure 4 shows a common method used for lead identification of transistors. The transistor manufacturer has placed a tab near the emitter. The collector can be identified as the farthest lead from the emitter, or you can identify the base and emitter by holding the transistor as shown. Moving in a clockwise direction, the leads are emitter, base, and collector. Some manufacturers have placed a red dot next to the collector to identify it. Going clockwise, the base is next and then the emitter. Other manufacturers use a color code for transistor leads. The emitter lead is yellow, the base lead is black, and the collector lead is red.

The service technician should always have available the manufacturer's data for all equipment serviced. These data sheets include a parts list and description of the parts. Without this list you might mistake one part for another. For example, the voltage regulator integrated circuits (ICs) shown in figure 5 have three leads coming from them and could easily be mistaken for transistors. Not all of the integrated-circuit chips have as many circuit leads and are as easy to identify as the low-power IC shown in figure 6.

Transistor Manual

Another helpful tool that every radio and television service technician should have available is a recent transistor manual. This publication gives up-to-date information on transistor designs, characteristics, applications, and lead identification. These manuals can be purchased at electronics supply houses.

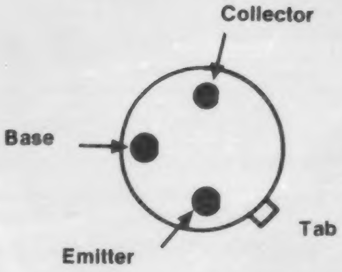

Fig. 4. Transistor lead identification

Transistor Testers

There are many transistor testers on the market today. Some of them are designed to test transistors after they have been taken out of the electronic circuit. Some of them test transistors in the circuit. Other testers will test transistors in or out of the circuit. Of course, a direct substitution of a new transistor for the one that is in question is always in order. Voltage measurement, signal tracing, resistance measurement, and substitution should still be the major troubleshooting and servicing approach.

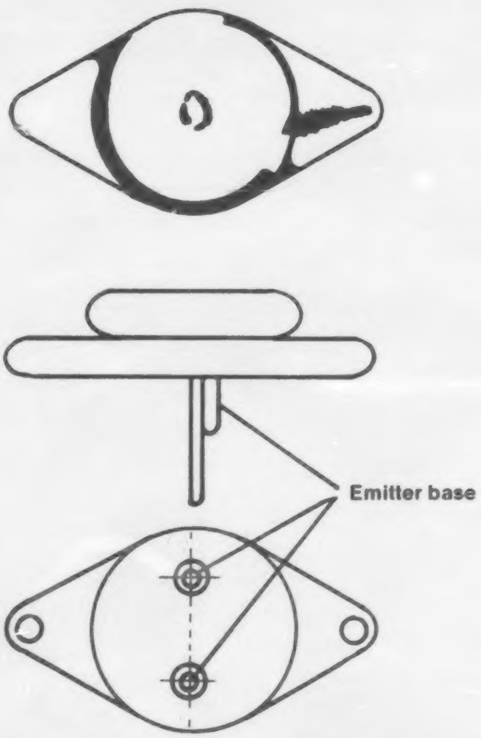

Fig. 3. Power transistor

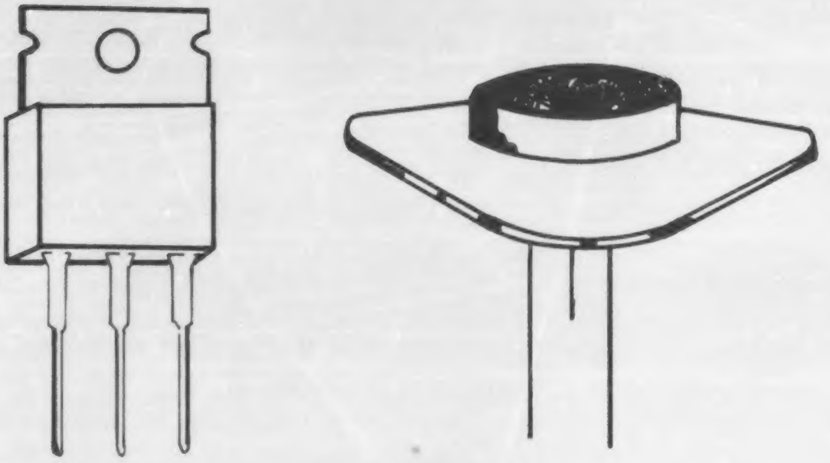

Fig. 5. Two types of voltage regulator integrated circuit

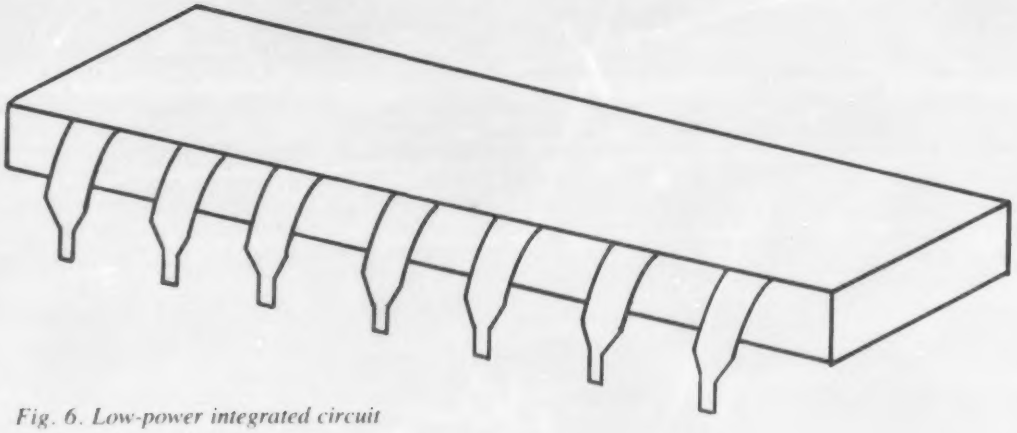

Fig. 6. Low-power integrated circuit

A transistor can be checked in or out of circuit with an ohmmeter. The resistance is measured in both directions between the transistor leads to check the "diode action." By switching the positive and negative leads of the ohmmeter, you can provide both forward-bias and reverse-bias through the ohmmeter's battery. In one direction there should be a very low resistance of only 200 or 300 ohms. When the ohmmeter leads are switched in the other direction, a high resistance of about 5K or 6K ohms should be read. This test is made between the emitter and the base and between the base and the collector to test the "diode action." The test can tell you if the transistor is shorted or open. If the resistance between two of the transistor leads turns out to be the same in either direction, the transistor is very likely to have a short or an open.

The silicon transistor requires a higher voltage to start the "diode action" than is available in many ohmmeter batteries. For this reason, a special in-circuit transistor tester would be superior, but in many instances the ohmmeter tests are just as satisfactory.

Exercise

1. How can the base of a transistor be compared to the control grid of a vacuum tube?
2. Which element of a vacuum tube can be compared to the emitter?
3. Which element of a vacuum tube can be compared to the collector?
4. How can you identify the three elements of a transistor when a small square tab is placed next to one of the leads?
5. How can you identify the three elements of a transistor when a red dot appears next to one of the leads?
6. How can you identify the three elements of a transistor when the lead wires are color-coded?
7. Why should you refer to the latest manufacturer's data when working on transistor circuits?
8. How is a transistor manual helpful?
9. What are six tools (or resources) mentioned in this assignment that would help you learn about transistors and service or troubleshoot transistor circuits?

Section

F

Basic Radio

F-1. Transmission of Sound
F-2. Frequencies and Channel Selection
F-3. The Superheterodyne AM Receiver
F-4. The RF Amplifier and Related Circuits
F-5. The IF Amplifier and Second Detector
F-6. The AF Amplifier and Volume Control
F-7. Basic Signal Tracing

F-1

Transmission of Sound

Objectives: After completing this assignment, you should be able to—

1. explain how sound signals are transmitted to a radio receiver;
2. tell what amplitude modulation is; and
3. compare frequency modulation to amplitude modulation.

A long-standing theory has been that all energy is transmitted by wave motion. Water waves, sound waves, and radio waves have some common characteristics. At some time, almost everyone has thrown a rock into a small stream or pond and watched the waves move on the surface of the water. Radio waves are radiated into space in a similar manner.

The term *radio* can be identified as the **transmission of signals through space**. These signals are transmitted by electromagnetic waves. When the word *radio* is used, it usually refers to the transmission of code and sound signals. Radar and television also rely on electromagnetic waves for their transmission.

Basic Radio Communication System

Essentially, a radio communication system is composed of a transmitter, a transmitting antenna, the communication medium (space), a receiving antenna, and a receiver. This basic radio communication system is shown in figure 1. Notice the different parts of the radio wave. Part of each wave moves along in contact with the ground. This is called the **ground wave**. It is ordinarily considered to be composed of two parts—a *direct wave* and a *surface wave*. The ground wave is used for short-range communications transmitted with low power at high frequencies. It is also used for long-range transmissions with high power at low frequencies.

Another part of the radio wave that moves upward and outward is called the **sky wave**. Some of this wave refracts (bends) back to earth when it contacts the ionized layers of space from about 40 to 350 miles above the earth. The sky wave is used at

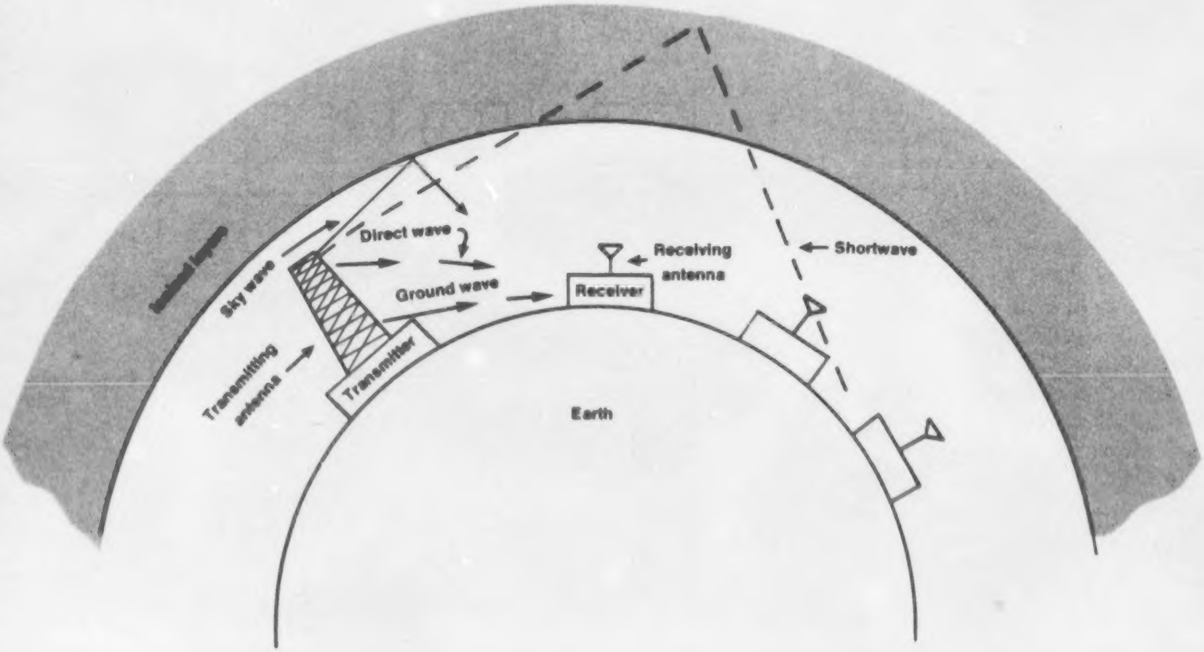

Fig. 1. Radio communication system

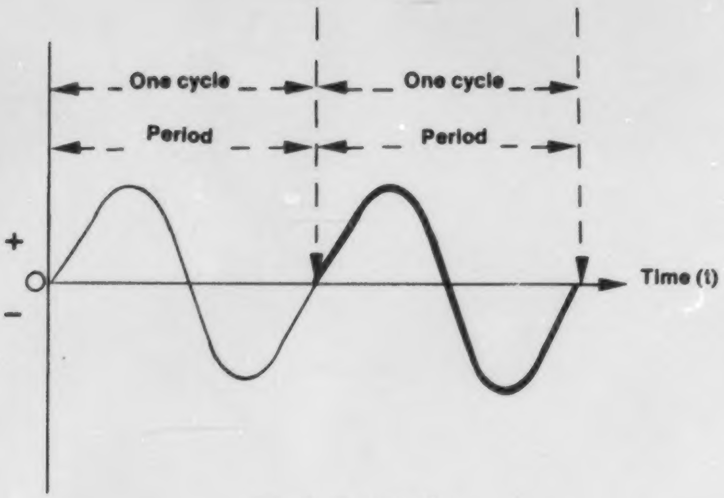

Fig. 2. The sine wave

night for long-range transmission at lower frequency. It also provides daylight long-range transmission at high frequency.

Cycles, Period, and Frequency

Earlier you learned how AC voltages and currents differed from DC voltages and currents. The AC quantities vary with time. The value of the voltage or current would be constantly changing as it was measured. The voltmeter must compensate for this by measuring the effective value of sine-wave voltages. The effective value is 0.707 of the peak AC voltage. It is the equivalent of DC voltage as far as power is concerned.

The unmodulated output of a radio transmitter, like the voltage from the wall outlets in your home, is a sine-wave voltage. Any AC voltage having a graphical shape like the one in figure 2 is called a **sinusoidal** (sign-u-soy-dull) **wave**.

In figure 2, the wave pattern consists of a positive rise and a negative fall that is repeated many times in rapid succession in a live circuit. From the start, or zero point, to point 1 is one *cycle* of the wave. Between point 1 and point 2 is another complete cycle. The time (t) it takes for the wave to complete one cycle is called the *period* of the wave.

The number of cycles per second, also called *hertz* (Hz), is still another way to describe the speed of the wave changes. This tells how frequent the changes are and is referred to as the *frequency* of the wave. To determine the frequency of a wave, the period of the wave is divided into 1. Frequency is the reciprocal of the period.

$$\text{frequency } (f) = \frac{1}{\text{period}}$$

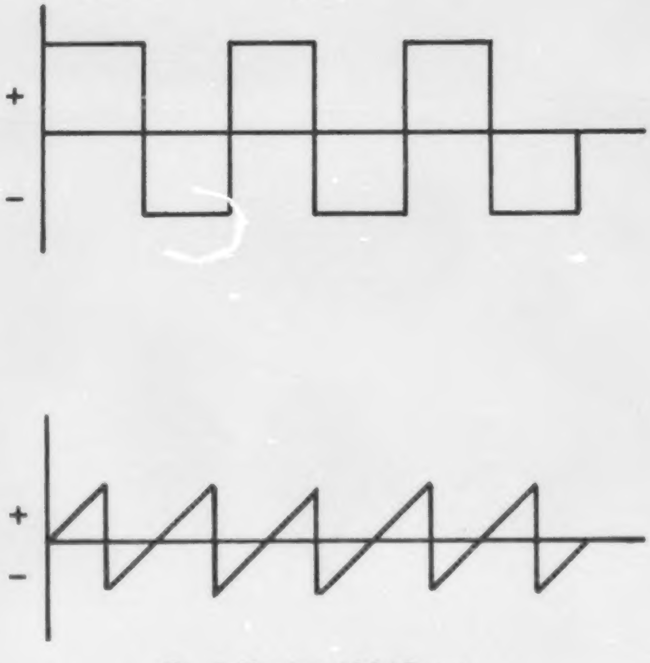

Fig. 3. Nonsinusoidal AC waves

An AC wave pattern can be in any shape. As long as the same shape appears on both the positive half cycle and the negative half cycle, it is an AC wave. Figure 3 shows two examples of AC waves that are not sine waves.

Phase Angle

Another term used to describe electrical waves is the *phase angle*. Two waves are compared through one cycle in figure 4. Notice that wave 1 and wave 2 start at 0° at the same time and finish at the 360° point at the same time. This means that they are *in phase*. The phase angle at which they are generated is the same for both waves. They are together at 90°, 180°, 270°, and 360°. If one wave leads or lags behind the other one, the amount of lead or lag is called the phase angle. It is measured in degrees.

In figure 5, wave 1 and wave 2 are 90° out of phase—that is, the phase angle is 90°. Wave 1 is a position 90° ahead of wave 2 when wave 2 is just at 0° and starting its positive half cycle.

Two waves are shown 180° out of phase in figure 6. The two waves are opposites, or flip-flops of each other. They both start at the same time at 0°, but wave 1 moves positive while wave

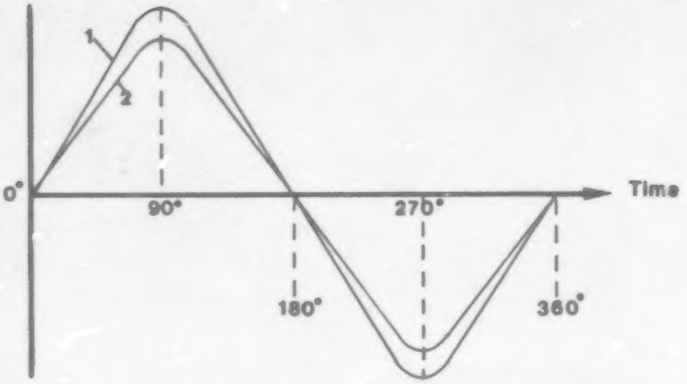

Fig. 4. Two waves in phase

2 moves in its negative half cycle. Wave 1 reaches its positive peak when wave 2 reaches its negative peak.

Basic AM Transmitter

An amplitude-modulated (AM) transmitter has the audio-frequency and radio-frequency signals combined so that the amplitude of the radio-frequency carrier waves varies at an audio-frequency rate. This is called **amplitude modulation**.

The block diagram for a basic AM transmitter is shown in figure 7. When speech or music is fed into the microphone, the force of the sound waves creates a voltage inside the microphone. Carbon granules on a crystal operate inside the microphone to cause this voltage. If a quartz crystal is used, a piezoelectric effect is brought about when the sound waves contact the crystal. In the microphone, sound energy is changed into audio-frequency (AF) electrical energy. This is called the *intelligence*. This intelligence passes on to the audio amplifier section where it is amplified and sent on to the modulator section.

If you recall the transistor amplifier circuits that you studied earlier, it will help you to understand oscillator circuits. A transistor oscillator acts like an amplifier with the exception that part of the output power is returned to the input circuit. This brings about a positive feedback, and the feedback starts oscillation. All of this must be done in the oscillator section in order to produce a signal of a higher frequency than the intelligence. This higher-frequency signal is called the *carrier signal*.

To produce the carrier frequency, a transistor oscillator would operate as shown in figure 8. You can see that the transistor oscillator is an amplifier with part of its output signal feeding back, in proper phase, to the input circuit.

The radio-frequency (RF) carrier frequency is amplified at the buffer amplifier section and delivered to the power amplifier section. Here it has the audio-frequency signal impressed

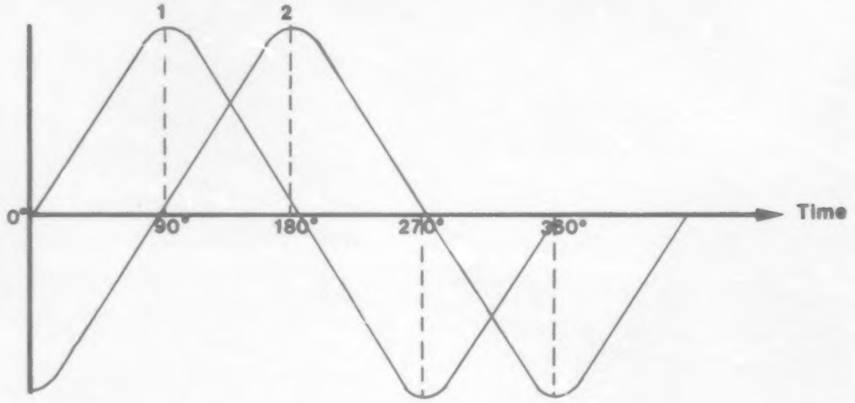

Fig. 5. Two waves 90° out of phase

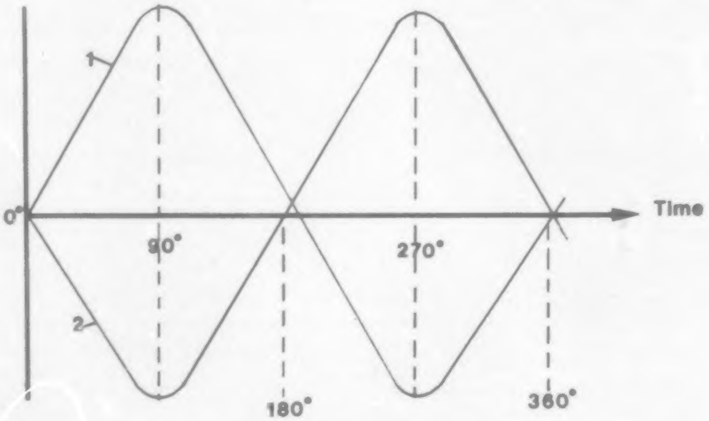

Fig. 6. Two waves 180° out of phase

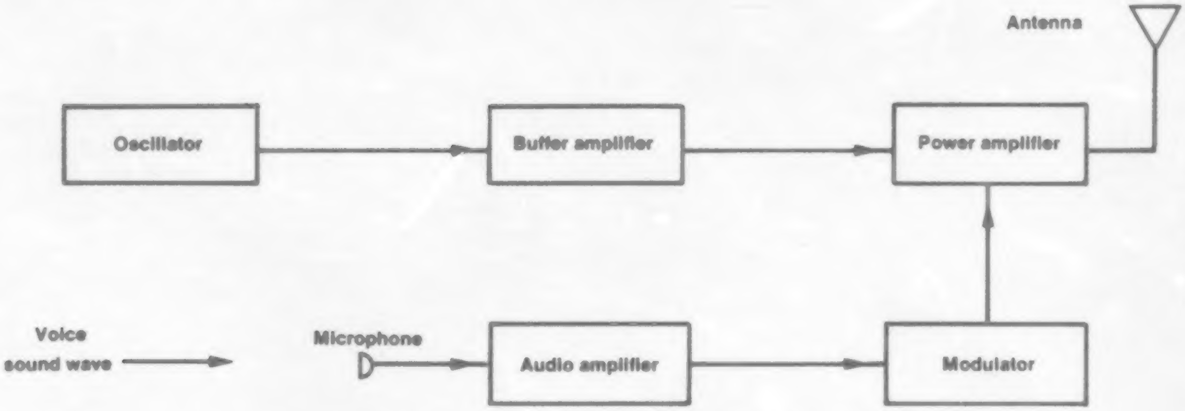
Antenna
Oscillator
Buffer amplifier
Power amplifier
Voice
sound wave
Microphone
Audio amplifier
Modulator

Fig. 7. An amplitude-modulated (AM) transmitter

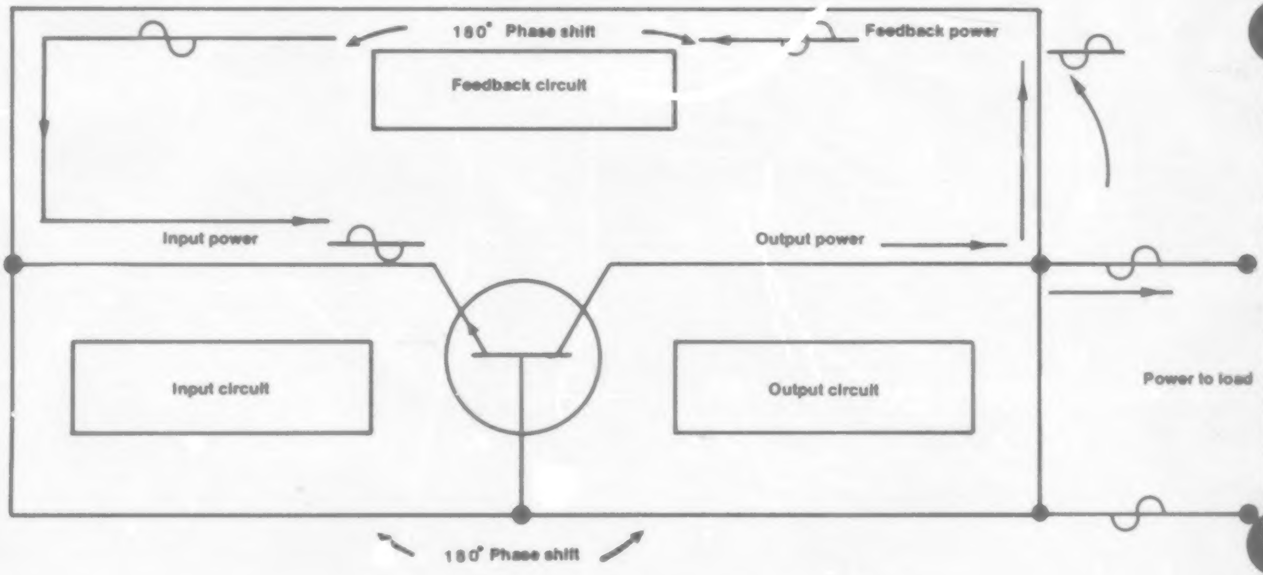
180° Phase shift
Feedback power
Feedback circuit
Input power
Output power
Input circuit
Output circuit
Power to load
180° Phase shift

Fig. 8. Block diagram of basic transistor oscillator

on it, as shown in figure 9. This modulated signal is called the *envelope*. The actual audio portions of the modulation are removed before transmission. Only the audio effect is left on the RF wave when it is radiated through the transmitter's antenna. The power amplifier section, through high-power amplification, causes a radio-frequency (RF) current to flow through the transmitting antenna. From the antenna it travels through space to receivers that are in reception range and tuned to the carrier frequency. These radio receivers are able to remove the audio component from the carrier. This is called *demodulation* or *detection*. The audio signal that has been detected is fed to a speaker or headset. This reproduces the original sound.

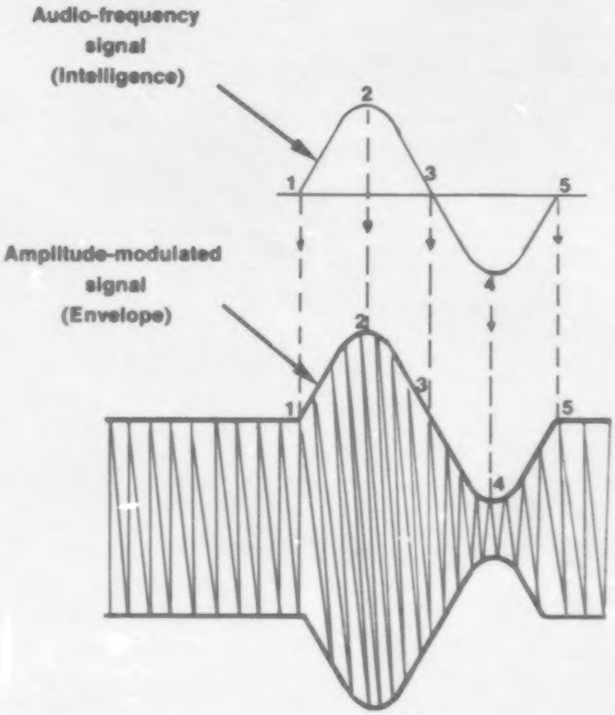
Audio-frequency signal (Intelligence)
1
2
3
4
5
Amplitude-modulated signal (Envelope)
1
2
3
4
5

Fig. 9. The AF signal impressed on the carrier

Frequency Modulation

You have just learned how the frequency of the carrier did not change in amplitude modulation. The amplitude of the carrier only would change at an audio-frequency rate. However, there is another reliable method that can be used to modulate the carrier RF signal. It is called *frequency modulation* or FM.

In FM transmission, there is no change in the amplitude of the carrier signal, but the frequency fluctuates a little above and below the average frequency of the carrier. These deviations of the carrier frequency are proportional to the strength of the modulating signal. The amount of carrier frequency variation depends on the magnitude of the modulating signal.

Figure 10 shows that there is a definite relationship between the magnitude of the audio-frequency signal and that of the frequency-modulated carrier signal below it. During the positive half cycle of the AF signal as it climbs to its peak (highest value of voltage or current), the modulated carrier below it shows that the frequency becomes slower. As the AF modulating signal moves downhill, becoming more negative, the frequency speeds up.

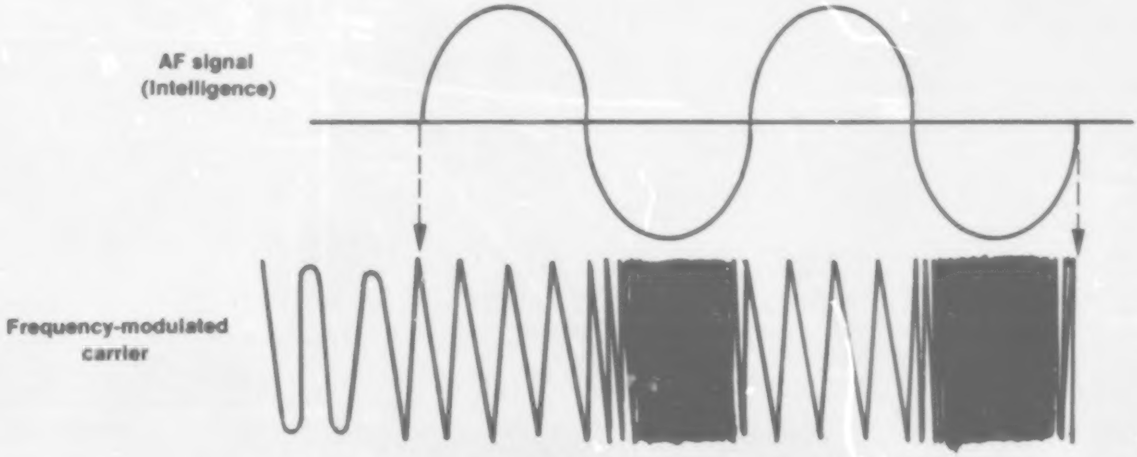

Fig. 10. Frequency modulation

Exercise

1. How are sound signals transmitted to a radio receiver?
2. What is amplitude modulation?
3. What is the fundamental difference between frequency modulation and amplitude modulation?

F-2

Frequencies and Channel Selection

Objectives: After completing this assignment, you should be able to—

1. compare standard AM radio transmission and television sound transmission;
2. tell how sideband frequencies are used in the transmission of sound waves;
3. discuss suppressed carrier transmission; and
4. explain the principle of channel width.

For standard AM radio transmission, the message content can be music, speech, or any other sound that can be detected by the human ear. All frequencies from about 30 to 15,000 Hz must be transmitted through a high-quality system for true reproduction of music. The waveform for music and speech is complex. It contains many individual sounds of different frequencies and amplitudes.

Radio Frequencies

Any frequency from 20,000 Hz is considered to be a *radio frequency*. However, only special government radio services operate radio equipment anywhere near that low a frequency. The commercial broadcast band of frequencies extends from about 550 kilohertz to 1,700 kilohertz (KHz). The FM broadcast band operates on frequencies of from 88 megahertz (88 million Hz) to 108 megahertz (MHz). Table 1 lists the common radio frequency bands, their abbreviations, and their range. The most widely used bands are the low frequency, medium frequency, high frequency, very high frequency, and ultra high frequency.

Television Sound Transmission

The picture signals for television broadcasting are transmitted by an AM transmitter. A composite television wave is quite different from a sound wave, because it has a very wide frequency range. Two separate transmitters are used by television broadcasting systems. One is an FM radio transmitter for the sound (audio) transmission. The other one transmits the picture (video) information. The two are associated very closely together. The Federal Communications Commission (FCC) has set many standards for the radio and television industry. One of these standards is that the audio signal be frequency-modulated on a carrier frequency 4.5 megahertz above the carrier frequency of the picture intelligence. The FCC has specified that the audio signal be transmitted by an FM system to avoid interference from the AM video signal.

Sideband Frequencies

Although the waveform produced from an AM radio antenna is in the form of one composite envelope, two other frequencies are present in the power amplifier besides the audio frequency and the carrier frequency. These two other frequencies are called **sideband frequencies**. The sidebands are related to the original two frequencies as sum and difference frequencies. The sum frequency is the sum of the audio-modulating frequencies and the RF carrier. This is the *upper sideband*. The difference frequency is the difference between the RF carrier and the audio-modulating frequencies. This is the *lower sideband*. These three frequencies of the carrier, upper sideband, and lower sideband appear simultaneously at the power amplifier's output. They add to form one composite envelope. This envelope containing the sidebands is transmitted into space where it is picked up by the antennas of radio receivers in the locality. If a carrier alone were transmitted without the sidebands, no message would be present. The actual message content is in the sidebands.

Table 1
Radio Frequency Bands

Frequency Band	*Frequency Range*
Very Low Frequency (VLF)	Below 30 KHz
Low Frequency (LF)	30 to 300 KHz
Medium Frequency (MF)	300 to 3,000 KHz
High Frequency (HF)	3,000 to 30,000 KHz
Very High Frequency (VHF)	30 to 300 MHz
Ultra High Frequency (UHF)	300 to 3,000 MHz
Super High Frequency (SHF)	3,000 to 30,000 MHz

Single Sideband Suppressed Carrier

The military use of single sideband (SSB) transmission during World War II led to its greater use after the war. Single sideband transmission is an alternative to standard AM transmission.

As you learned earlier, the carrier is needed to form the composite envelope to be transmitted, but the carrier itself need not be transmitted. Both sidebands have the same message content, so it is not necessary to transmit both of them. When one sideband is suppressed and the carrier is suppressed from transmission, it is called *single sideband suppressed carrier transmission*. The carrier frequency must be generated in the oscillator stage of a radio receiver to duplicate the original suppressed carrier.

Radio Channel Selection

A radio communication system that transmits a carrier and sideband frequencies must have a pathway of a specific width. This minimum width of frequency spread is called a *channel*.

The commercial radio broadcast band is extremely crowded. Because of this, channel width had to be limited. The *channel width* of a radio communications system is set after a study has been done to determine the minimum width that will allow acceptable transmission of the carrier and sidebands.

Exercise

1. What are the differences between standard amplitude-modulated transmission and television sound transmission?
2. How are sideband frequencies used in the transmission of sound waves?
3. What is suppressed carrier transmission?
4. What is the principle of channel width?

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F-3

The Superheterodyne AM Receiver

Objectives: After completing this assignment, you should be able to—

1. tell what *selectivity* and *sensitivity* mean in a receiver;
2. name the advantage and the disadvantage of the TRF receiver;
3. name the stages of a superheterodyne receiver; and
4. tell what each section of the superheterodyne receiver contributes to the operation of the complete radio receiver.

The TRF Receiver

The most widely used type of radio receiver is the superheterodyne receiver. This receiver was developed to overcome the disadvantages of its forerunner, the tuned radio-frequency (TRF) receiver. The TRF receiver block diagram is shown in figure 1. Only one stage of the RF amplifier is shown, but several RF amplifier stages were often used to improve its performance.

The main disadvantage of the TRF receiver was that it could not reject unwanted frequencies. The ability of a receiver to do this is called *selectivity*. The TRF receiver also lacked the ability to amplify certain desired frequencies in a uniform manner. This ability of a receiver is known as *sensitivity*. The TRF receiver did not have uniform selectivity or sensitivity over its frequency range. By increasing the number of RF stages, the selectivity and sensitivity could be improved to a certain extent.

The chief advantage of the TRF receiver was its simplicity. As you can see in the block diagram (fig. 1), the only remaining stages are the detector and the audio-frequency amplifier stages.

The detector takes the RF amplitude variations from the preceding stage, but only delivers audio variation to the input of the audio-frequency amplifier. In the detector stage, the demodulation or detection process is completed. The AM envelope is rectified to separate the intelligence from the RF carrier. The RF carrier is discarded by being filtered out.

At the final stage of the TRF receiver, the audio amplifier amplifies the audio signal so that it will be strong enough to operate a speaker or earphone.

The Superheterodyne Receiver

The superheterodyne receiver circuits are found in most receivers used in broadcasting television and general communications. Although the TRF receiver has its disadvantages, it does seem to operate better in solid-state microminiature circuits. These types of circuits lend a new opportunity for the TRF receiver to regain popularity.

Figure 2 shows a block diagram for an AM superheterodyne receiver, with one tuned RF amplifier. The same basic block diagram is shown in figure 3, except that the RF amplifier stage has been omitted. In the superheterodyne receiver, an RF signal is picked up from the antenna, amplified in the RF amplifier (see fig. 2), or fed directly to the converter stage (see fig. 3). From the converter (sometimes called *mixer*) stage, the process is the same for both types of receiver.

In the converter, the incoming signal is mixed (*heterodyned*) with a signal generated in the heterodyne oscillator. The heterodyne oscillator is also called the *local oscillator*. The incoming signal is changed to the pretuned intermediate frequency of 455

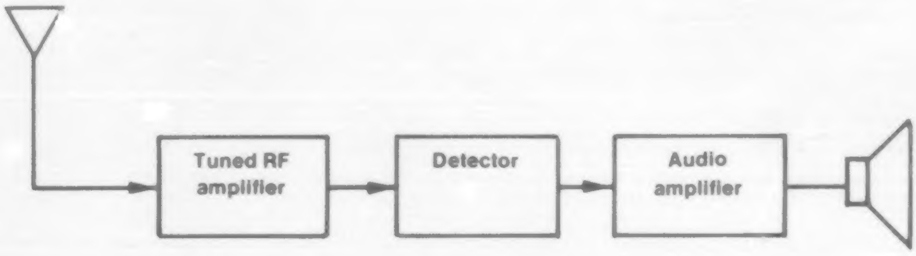

Fig. 1. Tuned radio-frequency (TRF) receiver

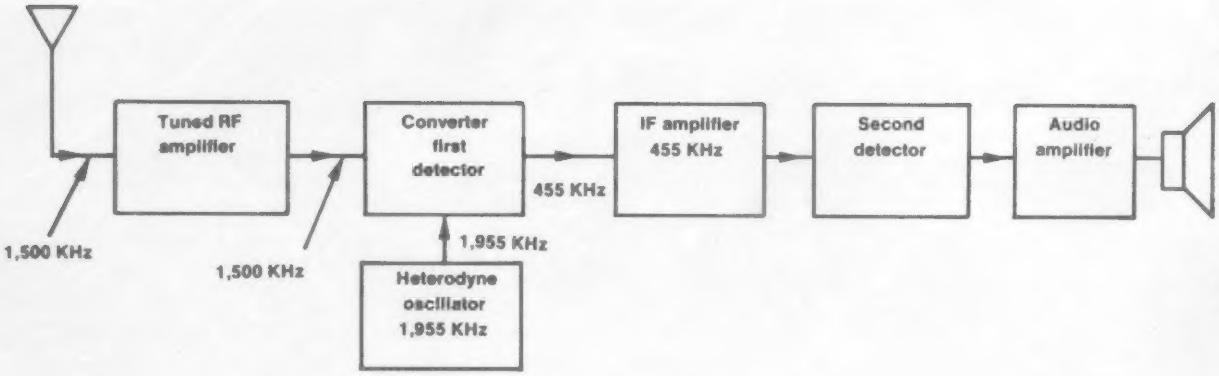
Tuned RF amplifier
Converter first detector
IF amplifier 455 KHz
Second detector
Audio amplifier
455 KHz
1,955 KHz
1,500 KHz
1,500 KHz
Heterodyne oscillator 1,955 KHz

Fig. 2. AM superheterodyne receiver with tuned RF stage

KHz. This process of producing the intermediate frequency is called **heterodyning**.

Four frequencies are produced at the converter's output by the mixing or heterodyning action. These are (1) the incoming signal, (2) the heterodyne oscillator signal, (3) the sum of the incoming signal and the heterodyne oscillator signal, and (4) the difference between the incoming signal and the heterodyne oscillator signal. The difference frequency is usually used. About all receivers use 455 KHz as the intermediate frequency. For example, assume that an incoming RF signal of 1,500 KHz is fed into the converter stage, where it is mixed with the signal produced in the heterodyne oscillator (1,955 KHz). The difference frequency is used as the intermediate frequency so the difference between 1,955 KHz and 1,500 KHz gives 455 KHz as the intermediate frequency.

The use of the intermediate frequency (IF) amplifier has helped to solve the problems of bandpass selectivity and amplification. Whenever a different incoming carrier signal is used (other than 1,500 KHz), the local oscillator frequency is adjusted so that the difference between incoming carrier and local oscillator will again produce 455 KHz as the intermediate frequency. Sometimes, in more expensive receivers, several IF stages will be used to improve sensitivity, selectivity, and amplification.

In the second detector stage, the modulated signal is completely demodulated. This separation of the intelligence from the RF carrier is called **detection** or **demodulation**. The AM envelope is rectified, and the RF carrier removed by being filtered out. RF amplitude fluctuations are fed into the detector input, and audio variations come out of the output.

In the audio amplifier—the final stage of the superheterodyne receiver—the audio signal is amplified. The amount of amplification required depends on the type of reproducer being used. A **reproducer** is any device that is able to take the amplified audio signal from the last detector stage and change this electrical energy into mechanical sound vibrations that can be heard by the human ear. This sound should duplicate, as much as possible, the original speech or music that was transmitted to the receiver. This duplication or reproduction of the original sound might be done with earphones or a speaker. Only one audio amplifier stage might be required if the

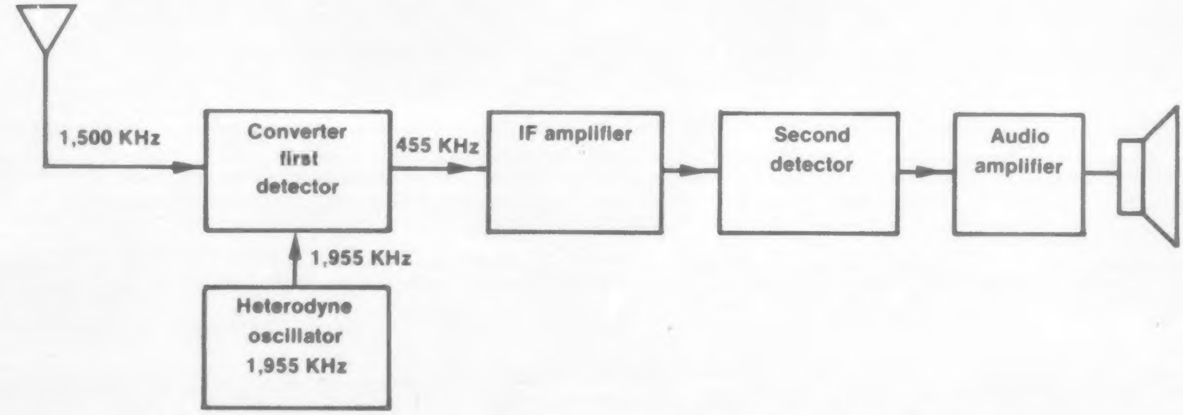
1,500 KHz
Converter first detector
455 KHz
IF amplifier
Second detector
Audio amplifier
1,955 KHz
Heterodyne oscillator 1,955 KHz

Fig. 3. AM superheterodyne receiver with antenna directly connected to converter stage

reproducer is a small speaker or earphones. To operate a large speaker, several audio amplifier stages might be required.

Exercise

1. What are *selectivity* and *sensitivity* in a receiver?
2. What was the main disadvantage of the TRF receiver?
3. What was the chief advantage of the TRF receiver? Explain.
4. What is the most widely used type of radio receiver?
5. What are the stages of a superheterodyne receiver with one tuned RF stage from antenna to reproducer?
6. What does *each section* of the superheterodyne receiver contribute to the operation of the complete receiver?

F-4

The RF Amplifier and Related Circuits

Objectives: After completing this assignment, you should be able to—

1. discuss the resonant frequency and tank circuits;
2. explain the advantages of RF amplifier circuits in an AM receiver;
3. tell how the mixer or converter stage is related to the RF amplifier;
4. explain what *class A biased* means; and
5. tell how a class A amplifier operates.

Some objects respond to sounds of certain pitches only. They are said to be "tuned" to those pitches. A common general science demonstration on sound involves the use of two tuning forks. When one of the forks is tapped, it begins to vibrate at a certain frequency and a particular ringing tone can be heard. The other fork has been designed or tuned so that it will respond to the frequency of that same tone. This is an example of what is called *mechanical resonance*.

Resonant Circuits

There is also an *electrical resonance* that is a very important part of a radio receiver. This resonant circuit is located primarily in the stage that receives its input signal directly from the antenna. When an RF amplifier is used in a superheterodyne receiver, the resonant circuit is placed in that stage. At least one RF amplifier is found in higher-quality receivers to give better reception of weak or distant stations.

A resonant circuit is what is commonly called a **tuned radio circuit**. You learned earlier about how a coil and a capacitor reacted in an AC circuit. At the *resonant frequency* (symbol f_0), the inductive reactance (X_L) is equal to the capacitive reactance (X_C).

When a coil and a capacitor are placed in a parallel-resonant circuit, as shown in figure 1, it will be resonant at a particular frequency. This is called a **tank circuit**. It will react at the resonant frequency in a similar manner to the tuning fork which vibrated at a particular tone. The circuit contains an oscillatory current, which charges the capacitor. The charged capacitor discharges its current into the coil. The coil then returns the current to the capacitor. This oscillation would continue almost indefinitely when the variable capacitor C_1 has been tuned to the resonant frequency. If this resonant frequency is at the same frequency as the incoming carrier signal, the tuned tank circuit responds very strongly. Other signals at frequencies near the tank resonant frequency will be rejected. The ganged type of capacitor, which you learned about earlier, is used for radio tuners so that several circuits can be adjusted to the same resonant frequency at the same time.

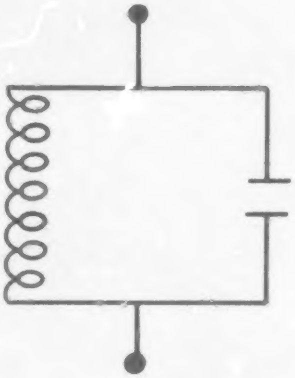

Fig. 1. Resonant tank circuit

RF Amplifier Operation

The RF amplifier shown in figure 2 uses a P-N-P transistor circuit. A tank circuit is a part of the antenna circuit. The transformer's (T_1) primary coil and the capacitor (C_1) form the tank circuit. A broadcast signal induces a current in the antenna. Currents at or near the tank's resonant frequency cause the tank to oscillate. These oscillations are coupled from the transformer primary to the secondary. It is then applied to the base of the transistor (Q_1). Collector current will then vary in step with the input signal, and an amplified signal across the collector tank circuit is the result. The primary of transformer T_2 and capacitors C_4 and C_5 form this collector tank circuit.

The DC voltage supplied by the power supply is represented by V_{CC}. A negative bias is supplied to the collector of Q_1 because it is a P-N-P transistor. The emitter is biased through R_1. Capacitors C_2 and C_6 prevent unwanted RF variations from reaching the power supply V_{CC}. The collector tank circuit and the antenna tank circuit are both adjusted to the same resonant frequency through the ganged inductors T_1 and T_2.

The variable tuning capacitors C_1 and C_5 are added in the RF amplifier circuit to compensate for differences between ganged sections. These tuning capacitors are set for minimum capacitance at the high-frequency tuning range during alignment procedures.

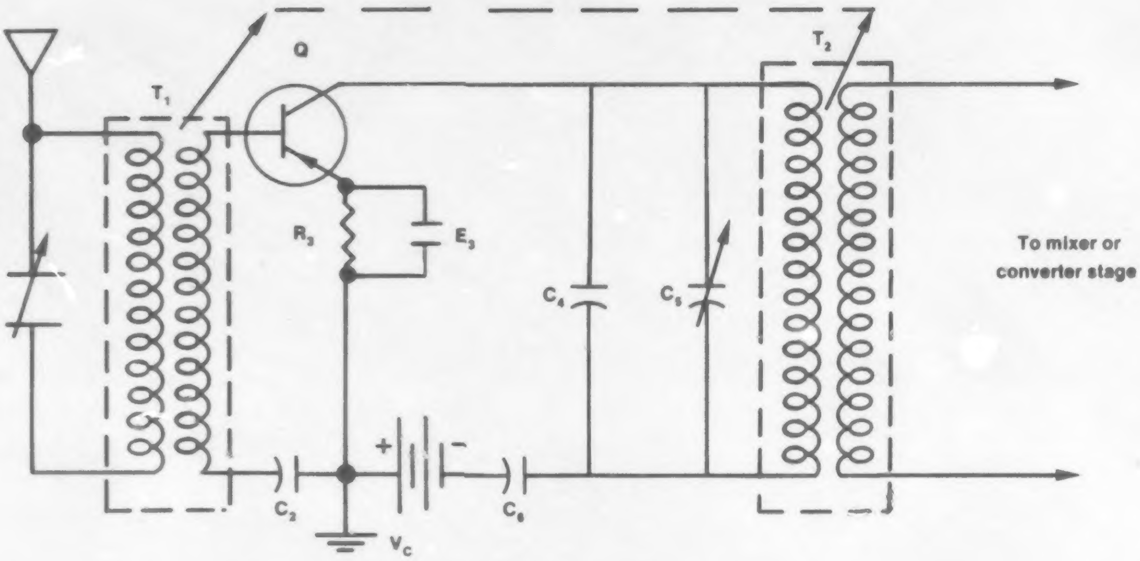

Fig. 2. RF amplifier

They are adjusted or aligned for maximum capacitance at the low-frequency tuning range. These standard adjustments that are made to meet the specifications given in the manufacturer's data sheets are called *alignment procedures*.

The output of transformer T_2 contains the amplified signal that is delivered from the secondary of T_2 to the converter or mixer stage of the RF amplifier. Sometimes the mixer and the local oscillator are combined into one stage that is called the converter. When the mixer is a separate stage from the local oscillator, the stage immediately following the RF amplifier stage is called the mixer stage. The same function is achieved whether a mixer or a converter stage is used. This function is to mix the input signal with the signal delivered from the heterodyne oscillator to deliver the frequency of 455 KHz to the IF amplifier.

An RF amplifier has several basic requirements. One of these is that it must amplify the input signal voltage without distortion. To do this, the transistor in the circuit must be biased for what is called *class A operation*.

Class A Amplifier

Before you learn how a class A amplifier operates, you must know about the two limits of transistor action and the proper bias of the transistor.

One of the two limits of transistor action is called **cutoff**. You learned earlier that a forward bias must be applied to a transistor for it to conduct continuously. Sometimes a transistor must be biased so that it will not conduct. The base is not forward-biased with respect to the emitter. Under this condition of reverse bias, the transistor is said to be at cutoff. In other words, the transistor reaction is as if there were an open circuit between the emitter and the collector.

The other limit of transistor action is called **saturation**. When the base to emitter junction is forward-biased, a transistor will conduct. If a sine wave signal is fed into the base, this increases the forward bias on the base, and conduction will increase. At the point where any increase in forward bias or increase in sine wave amplitude will no longer increase conduction, it is called saturation.

When an amplifier is said to be operating as a class A amplifier, it is *class A biased*. This means that the waveform at the collector output is the same shape as the input waveform but larger in amplitude. A class A amplifier operates between cutoff and saturation, as shown in figure 3. The input signal is amplified only when the signal does not exceed the limits for cutoff and saturation. Notice the 180°

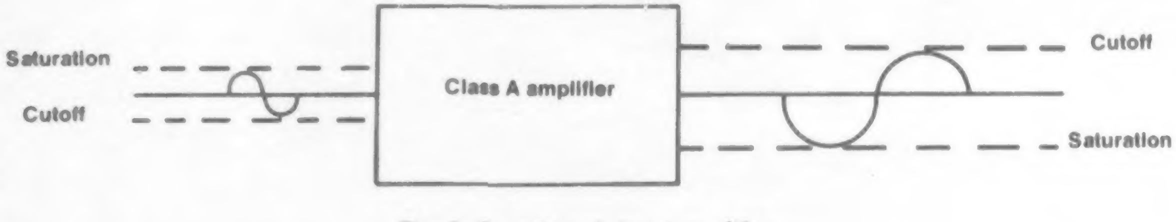

Fig. 3. Operation of class A amplifier

phase reversal from the input wave to the output wave in figure 3. Remember that this will always happen when the transistor output is taken from the collector and the input applied to the base. It does not matter whether the transistor is an N-P-N type or a P-N-P type. The reason for this is that the sine wave on the input side of the amplifier is a *current sine wave*. The sine wave at the output is a *voltage sine wave*.

You learned earlier that the transistor is a current-operated device, so it is current we observe in the input circuit. This input circuit determines the transistor action. It is the voltage that is amplified that we observe in the output. The key to understanding this complete reversal of phase is that, as the *current increases* from emitter to collector, the *voltage* across the transistor *decreases*. As the current moves through its positive half cycle, the voltage is moving through its negative half cycle. When the circuit is plugged in or turned on at time (t) equals zero, the current begins to increase and graphically its sine wave begins to climb. At this same time, the voltage begins to decrease and graphically its sine wave begins to move negative from the zero point. Of course, when the current sine wave and the voltage sine wave have completed one cycle, you see the two sine waves exactly 180° out of phase with each other.

Exercise

1. What is the purpose of resonant tank circuits?
2. What are the advantages of RF amplifier circuits in an AM receiver?
3. How is the mixer or converter stage related to the RF amplifier?
4. What does *class A biased* mean?
5. How does a class A amplifier operate?

Objectives: After completing this assignment, you should be able to—

1. tell the purpose of the intermediate frequency (IF) amplifier;
2. tell how the IF amplifier contributes to the operation of the receiver; and
3. explain the role of the second detector stage of the receiver.

F-5

The IF Amplifier and Second Detector

From the block diagram of the superheterodyne receiver in Assignment F-3, you learned that the intermediate frequency (IF) amplifier receives its input signal from the mixer stage. If a converter stage is used in place of the mixer, then the IF amplifier receives its input signal from the converter stage. The superheterodyne receiver includes at least one IF amplifier located between the mixer (or converter) and the detector stages. This is necessary because the amplitude of the signal coming from the mixer is so weak that it needs further amplification before it is ready to be fed into the detector stage.

IF Amplifier Operation

The operation of the IF amplifier is quite similar to that of the RF amplifier. However, the IF amplifier circuits are tuned to a particular resonant frequency while the RF amplifier tuned circuits vary in frequency over a wide range.

A transistor IF amplifier is shown in figure 1. The primary coil of transformer T_1 and capacitor C_1 form the tuned input circuit. This circuit is also the output tank circuit of the mixer stage. You learned earlier that this circuit is tuned to the intermediate frequency (455 KHz, 456 KHz, or 465 KHz in most receivers). The adjustment of a powdered iron core (arrow shown in figure 1 over the primary) is necessary to tune the primary of T_1. The secondary coil is untuned. The primary coil of T_1 has been tapped with its lead connected to the input terminal as shown. This allows the impedance of the tuned circuit to be matched to the output impedance of the mixer. Resistors R_1 and R_3 form a voltage divider and bias network. The resistors cause the voltages to drop to the proper bias voltages for class A operation. Resistor R_2 provides the emitter bias.

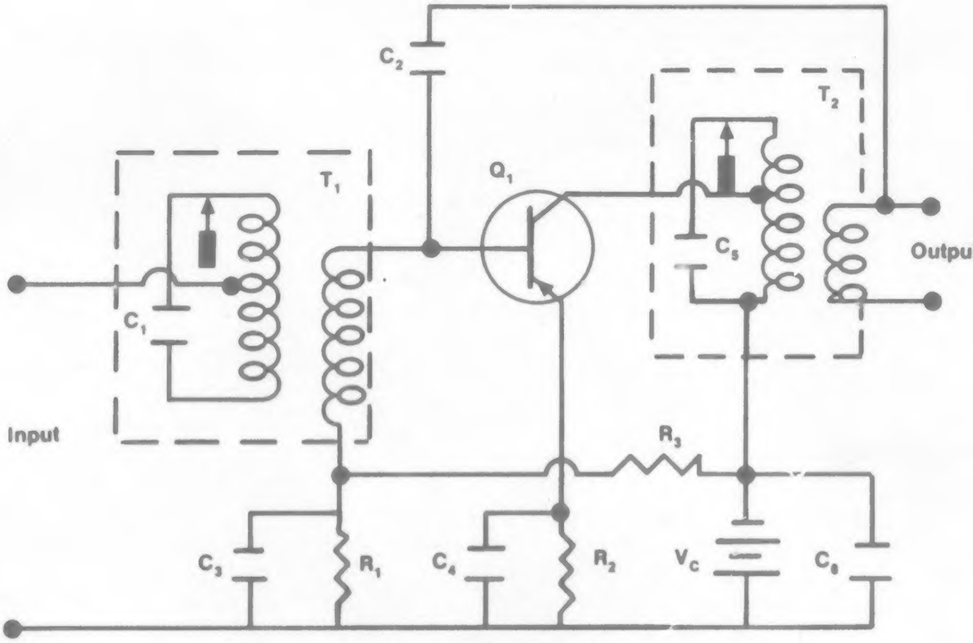

Fig. 1. IF amplifier

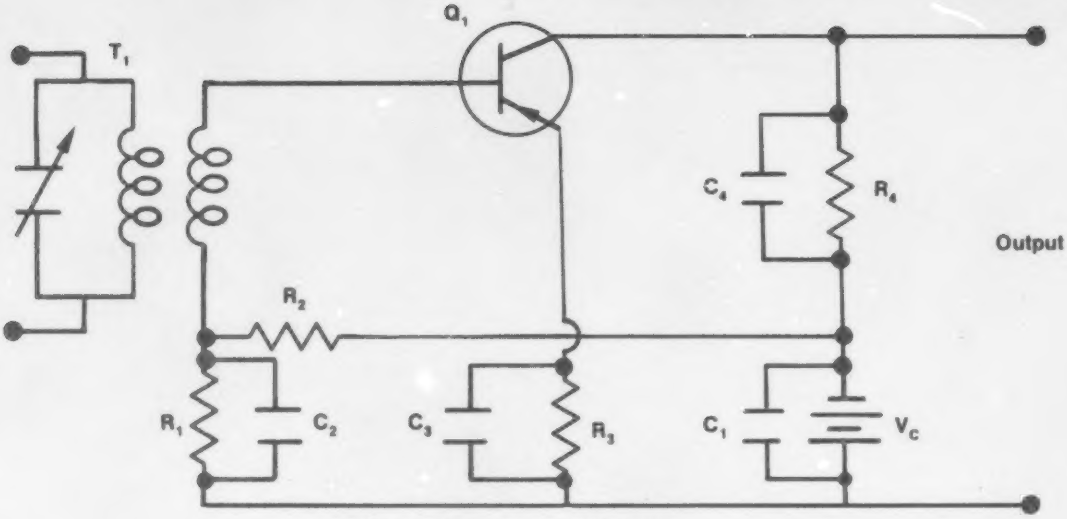

Fig. 2. The transistor detector

The P-N-P transistor Q_1 is operated as a *common emitter* (CE) circuit. The emitter is common to the input and the output. This common emitter operation provides a high power *gain*.

Amplifier Gain

You learned earlier that amplification makes a signal larger. A small signal controls a large current through the transistor. An amplifier's *gain is the number of times the transistor will increase the input signal*. An amplifier is designed for either voltage or current gain. Most power amplifiers are current gain amplifiers. The gain is the ratio of output signals to input signals. For example, if the input is 100 milliamps (MA) and the output is 500 MA, then the gain is:

$$\text{Gain} = \frac{\text{output current}}{\text{input current}}$$

$$= \frac{500 \text{ MA}}{100 \text{ MA}} = 5$$

The Detector Stage

The process of detection is considered to be the opposite of modulation. It is a method of recovering the intelligence from a signal. The simple diode detector is the oldest method used for detection. It is inexpensive and reproduces the message signal waveform quite efficiently. However, the diode detector is not able to amplify the incoming signal. Its output voltage is even a little less than the input voltage. The diode detection process is responsible for this signal loss. Sometimes it is necessary to detect a signal of very small amplitude. Since the signal is small to begin with, this slight loss may be intolerable in some cases. It is necessary, in many instances, to use a device that is more sensitive to small variations in the signal than the diode. The transistor detector circuit was developed to solve this problem.

The Transistor Detector

The actions of detection and amplification are combined within the transistor detector. This device is shown in figure 2.

Resistors R_1 and R_2 form a voltage divider circuit (or network) to provide the DC (no signal) forward bias. Capacitors C_1, C_2, and C_3 are called RF bypass capacitors. They prevent radio-frequency signal voltages from developing across the DC power supply bias resistor R_1. Remember that the bias resistor drops the voltage to the proper value of voltage to bias the base of the transistor. Since the transistor being used is a P-N-P type, the DC power supply (V_C) must be hooked up so the negative terminal is applied to the collector lead of transistor Q_1.

When a modulated IF signal is applied to the primary coil of transformer T_1, it causes voltage fluctuations at the IF rate to develop across the secondary of T_1. The result of this is that collector current is reduced. Positive alternations of the induced signal, in the secondary, oppose the forward bias. Of course, this reduction in forward bias applied to the base reduces the flow of current from emitter to collector. This accounts for the reduction of current at the collector output. In contrast to this action, the negative alternations aid forward bias and increase collector currents. Now you can see how the collector current must vary at an IF rate. These collector current variations are applied to the parallel circuit consisting of resistor R_4 and capacitor C_4. The high-frequency waves are filtered out by the filter capacitor C_4. The DC voltage developed between the collector output and ground varies in step with the original signal intelligence.

Exercise

1. What is the purpose of the intermediate frequency amplifier?
2. How does the IF amplifier contribute to the efficient operation of a receiver?
3. What is the role of the second detector stage of a receiver?

Objectives: After completing this assignment, you should be able to—

1. tell the basic operation of a driver amplifier;
2. discuss volume control and its relationship to the audio-frequency (AF) section of a receiver; and
3. explain the principles of operation for an audio power amplifier.

F-6

The AF Amplifier and Volume Control

In a previous assignment you learned how sound energy can be converted into electrical energy by means of a microphone. This electrical energy can then be transmitted to a receiver where it is changed back into sound by means of headphones or loudspeakers. It is necessary, somewhere in this process, to amplify or increase the volume of the signal being transmitted. An **audio amplifier** accomplishes this amplification while the signal is in the electrical state.

A well-known law of physics states that "energy can neither be created nor destroyed but changes from one form to another." Since energy cannot be created, the signal cannot be amplified without taking energy from somewhere else. The varying signal voltage is used to control the energy output of a direct-current source such as a battery or power supply. The output of an amplifier stage is this controlled energy (direct current) of greater magnitude.

You learned earlier that all of the bias voltages applied to the elements of a transistor or vacuum tube are DC voltages. The only AC voltages are the AC signal voltages that are fed into the base of transistors or the grid of vacuum tubes. It is very important to remember these facts about the operation of electronic circuits found in radio and television sets.

Classification of Audio Amplifiers

Audio amplifiers can be classified according to the operating conditions of the transistor or vacuum tube that is used in the particular amplifier stage. The classifications commonly used for audio amplifiers are *class A*, *class AB*, and *class B*. You have already learned the operating conditions of the class A amplifier.

A **class AB** amplifier has its collector current flowing during over half the cycle of the AC signal at the base of the transistor. The collector current also must flow for less than one complete electrical cycle of the AC signal.

A **class B** amplifier is biased so that the collector current will be cut off for one half cycle of the input signal. Collector current will only flow for one half of each cycle of the AC input signal.

The advantages of class B operation are that, under no signal conditions, there is a very low collector current and there is better power efficiency than in the other classes of amplifiers.

Power Requirements of Audio Amplifiers

The amplifier stage that is not designed to have high output power to operate the transducer (earphones or speaker) is called a *low-level amplifier*. This type of amplifier is designed to be a "signal amplifier" and is also called a *driver amplifier*.

The term *power amplifier* is used to designate a high-level power circuit. In a two-stage audio amplifier, the final stage that provides the power to operate the transducer is the power amplifier. The audio amplifier stage immediately preceding the power amplifier is the low power level amplifier. It is called the driver amplifier because it amplifies the signal that is used to drive the power amplifier.

The Driver Amplifier

A basic low-level amplifier circuit is shown in figure 1. In this circuit, a P-N-P transistor is used. Notice that the emitter is connected to the conductor that is common to both the input and the output. This is a *common-emitter connection*, which is used in most audio amplifiers.

The input circuit is forward-biased because of the effect of the current passing through the base-emitter junction. Resistor R_B establishes the operating point of the transistor by limiting the bias current.

When the input signal is into the positive half cycle, the forward bias at the base is decreased. This causes a decrease in collector current through the load resistor R_L. At this time there is less voltage drop across R_L. The collector voltage increases toward the negative bias voltage established by V_C.

The opposite result is brought about during the negative half cycle of the input signal. The forward bias is increased, and this causes the collector current through R_L to increase. The final result is that the collector voltage becomes less negative. The input and output voltage waveforms show a 180° phase reversal and a voltage gain. The signal voltage has been increased to a value that will be suitable to drive the power amplifier.

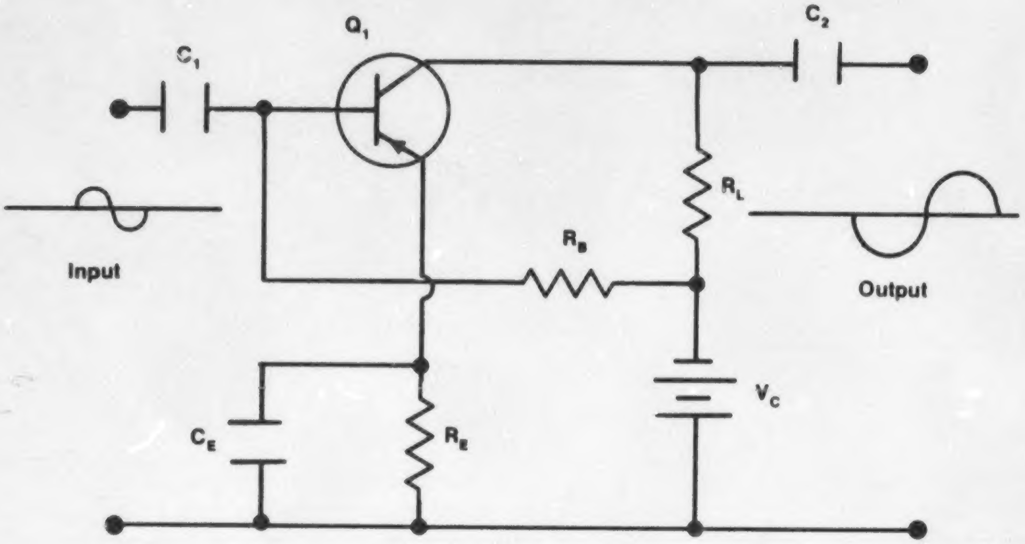

Fig. 1. AF amplifier

Volume Control

Some means of manual control of the output signal level is a necessary part of the AF section of any receiver. This control ordinarily varies the amplitude of the signal applied to the input junction of the first audio stage.

One method of volume control is shown in figure 2. In this two-stage amplifier circuit, the variable resistor R_2 is used as the volume control. As you learned earlier, this volume control device is also called a potentiometer. The load resistor R_1 produces the output signal of transistor Q_1. Capacitor C_1 delivers the coupled signal from Q_1 to R_3 and R_2, the parallel resistors. It is also carried to the input junction of Q_2.

Resistor R_2 controls the volume by varying the base-emitter bias of transistor Q_2. This bias can be varied from its maximum value to zero by turning the volume control knob. The collector load resistor R_6 produces the output signal from transistor Q_2.

The Audio Power Amplifier

The last stage of a series of audio amplifiers must always be designed to obtain maximum power output.

Phase-Splitter Driver Stage

Some audio circuits require the use of

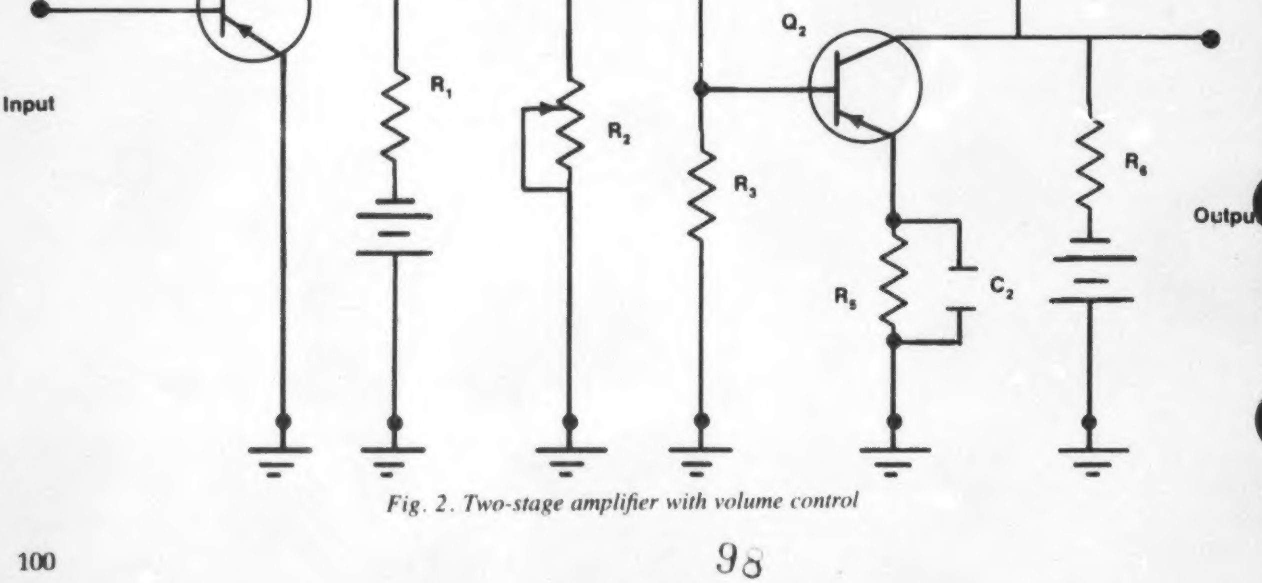

Fig. 2. Two-stage amplifier with volume control

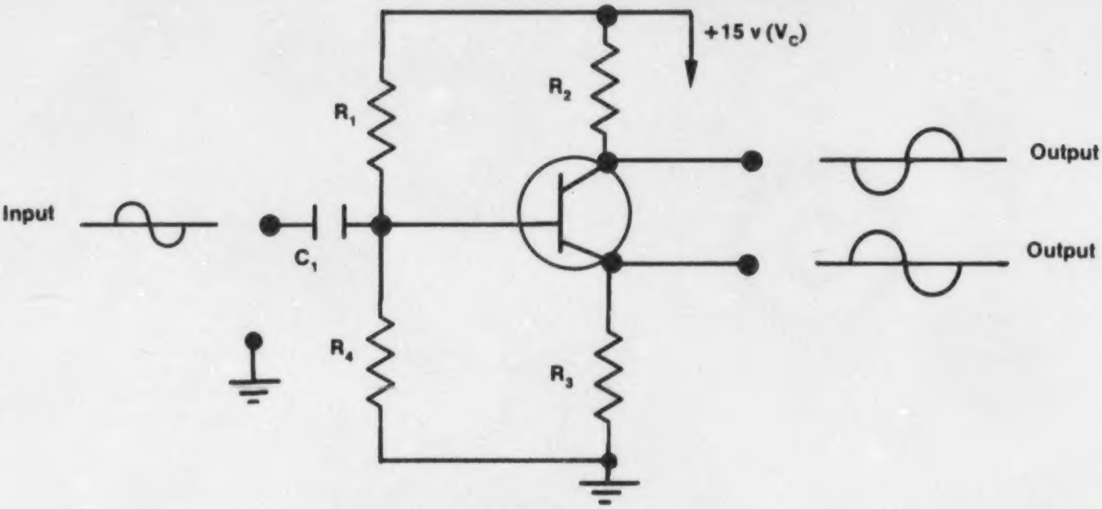

Fig. 3. Phase-splitter

two input signals 180° out of phase. The *phase-splitter circuit* is used for this purpose. As shown in figure 3, a single input signal applied to the base of the N-P-N transistor produces two signals at the output. The two signals are of equal amplitude but are 180° out of phase. The transistor is forward-biased for class A operation.

The collector resistor R_2 and the emitter resistor R_3 must be of equal value. Since the same current flows through R_2 and R_3, the voltage drops must be the same at both resistors (by application of Ohm's law). The transistor causes a phase reversal of the input signal at the collector output. However, there is no phase reversal at the emitter output. The result is that the two output signals are produced 180° out of phase with each other.

Transformer Phase-Splitter

Another method of phase-splitting is by means of a center-tapped transformer. The center tap allows the secondary coil to perform like two separate windings, as shown in figure 4. With reference to the center-tapped common ground, the two output signals are of equal amplitude and 180° out of phase.

Push-Pull Transistor Amplifiers

The phase-splitter circuits you have just studied have been designed for use in what is called a *push-pull circuit.* The push-pull circuit offers much more output power than that of a single-ended amplifier circuit. For this reason, it is often used as a final stage power amplifier, as shown in figure 5.

This push-pull amplifier consists of two common-emitter amplifier circuits connected back to back. Transformer T_1 is the phase splitter, which delivers the two out-of-phase signals to transistors Q_1 and Q_2. The top half of the push-pull circuit is from the negative power supply ($-V_C$) through the upper half of transformer T_2 through Q_1 and the emitter resistor to ground. The lower half of the push-pull circuit is from $-V_C$ through Q_2 and the other emitter resistor to ground. The collector load is distributed equally over each half of the output transformer T_2. The transformer action combines the signals from each half into one smooth output signal. This output from the push-pull amplifier is similar to the in-

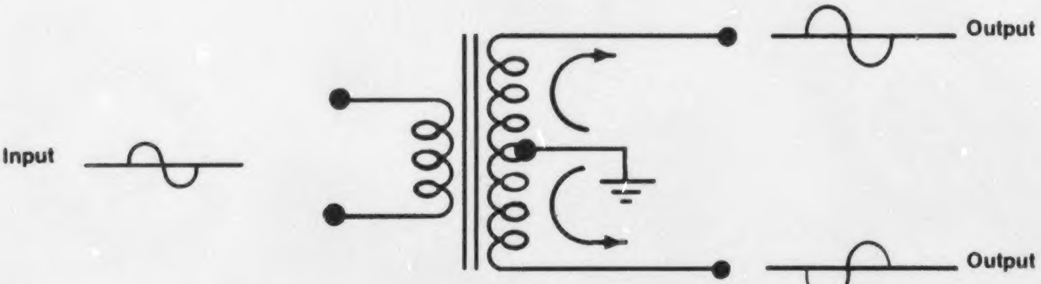

Fig. 4. Center-tapped transformer as phase-splitter

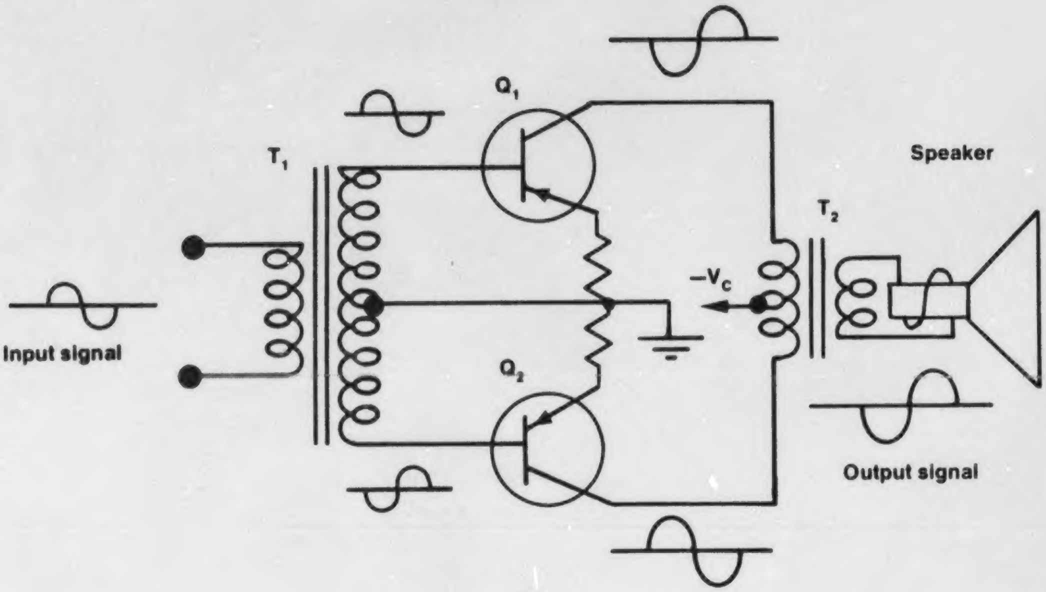

Fig. 5. Push-pull power amplifier

put signal but is much more powerful.

Push-pull amplifiers can be biased for either class A or class B operation. However, they are usually biased for class B operation because larger power outputs are possible with a minimum drain on the power supply.

Exercise

1. What is the basic operation of a driver amplifier?
2. How is the volume control related to the audio-frequency (AF) section of a receiver?
3. What are the principles of operation for an audio power amplifier?

Objectives: After completing this assignment, you should be able to—

1. compare a schematic drawing of a basic radio receiver circuit to the pictorial drawing of the same circuit;
2. tell how the input signal waveform changes as it comes from the antenna and passes through all the stages of a basic receiver;
3. tell how a signal generator and an oscilloscope can be used for troubleshooting; and
4. discuss the use of a commercial signal tracer.

F-7

Basic Signal Tracing

In order to be succesful in the radio and television servicing business, you should be able to identify electronic circuit components and relate them to the schematic drawing. You should also be able to do just the opposite—relate the schematic drawing to actual circuit components. Review the previous assignments that contain illustrations showing the physical appearance of various electronic parts. Compare the physical appearance of each part to the schematic symbol that you have learned represents it. As you look at these illustrations or the illustrations in electronic parts catalogs, draw the electronic symbol used for each part. You may be surprised to find out that you know the symbols for most of them.

Basic Circuit Tracing

The schematic drawing in figure 1 represents a transistor phase-splitter circuit. For electronic circuits there is a high side and a low side. Remember that the top half (the collector side) of the drawing must be more positive than the bottom half for current to flow through the transistor. The top side of the circuit connects to the positive terminal of the 9-volt battery. Remember that the hooked lines cross over the output but do not connect. The low side connects to the negative terminal. The base is lower or more negative than the collector. The emitter is still lower or more negative than the base. You can see that the negative side of the power supply is also connected to the common ground. Capacitor C_1 blocks the direct current and allows only the AC signal current to pass through to the base, as you learned earlier. The resistors are voltage dividers providing proper bias voltages to the transistor.

Compare the pictorial drawing in figure 2 of the same phase-splitter circuit. A 9-volt battery and the other circuit components are shown as they would actually appear. Using your finger or a pencil as a pointer, trace through the circuit shown as a schematic drawing (fig. 1), and then do the same with the pictorial drawing (fig. 2). When you have done this, you will see that the two drawings are really the same.

There are many different ways to draw the same schematic or pictorial drawing without changing the connections. On another sheet of paper, draw your own version of figure 1 and figure 2.

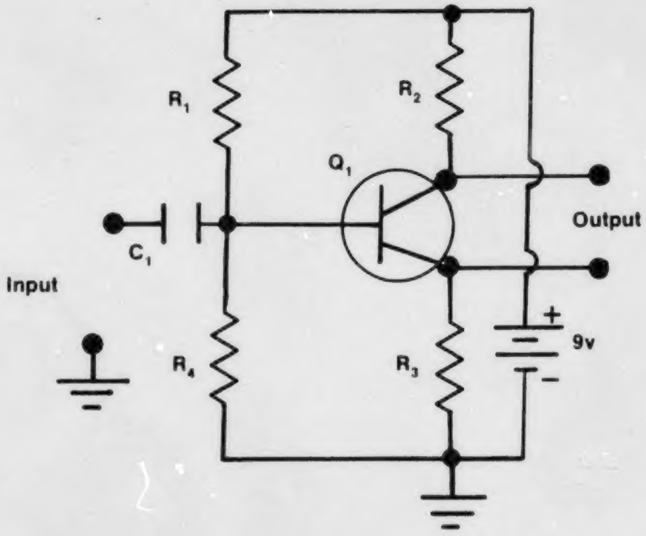

Fig. 1. Schematic drawing of phase-splitter circuit

Signal Tracing

All that you have learned about the block diagram of the superheterodyne receiver and the electronic circuits in each of those stages should begin to go together now like the pieces of a jigsaw puzzle.

When you can trace a radio signal all the way from the receiving antenna to the transducer through each stage of a receiver, you will have a good understanding of the entire process. Being able to follow the signal from its origin to the point where it becomes useful is called *signal tracing*. A signal must change form many times before it takes a usable form and is able to operate the transducer.

To understand what happens in the overall process of a signal moving through a receiver, carefully study figure 3. First, look at the section between the converter stage and the antenna. The input waveform enters the RF amplifier where it begins its first change. Notice how the output of the RF stage has a greater amplitude than the input side. Now look at the converter stage. You learned earlier how the converter changes the amplified RF signal into a lower frequency signal. This is the intermediate frequency signal. The change in the signal that is accomplished in the converter is necessary because the lower frequency signals can be amplified more easily. It is important to remember that the input signal for the converter stage is also the output signal from the RF amplifier stage. The same concept holds true between any two stages of the receiver.

Now focus your attention on the IF amplifier block. The IF stage enlarges (amplifies) the IF signal that was received from the converter. The low frequency signal develops a larger amplitude, as you can see, between the IF amplifier block and the detector block.

At the detector stage, the carrier signal is discarded. The IF signal is changed back into the original shape of the audio-modulating waveform that was present in the radio transmitter. This is shown as the output of the detector and input of the audio-frequency (AF) stage. The detector has reproduced the original audio message (intelligence), but it still does not have enough power to operate earphones or a speaker.

In the audio-frequency stage, the audio signal is amplified to the point where it will operate a transducer. The speaker reproduces the original sound that entered the microphone of the radio broadcast transmitter.

Special Signal-Tracing Equipment

Special test equipment can be used for troubleshooting and making service adjustments on radios and televisions. The three most widely used signal-tracing tools are the signal generator, the oscilloscope, and the signal tracer.

The **signal generator** can be adjusted so as to produce a signal of

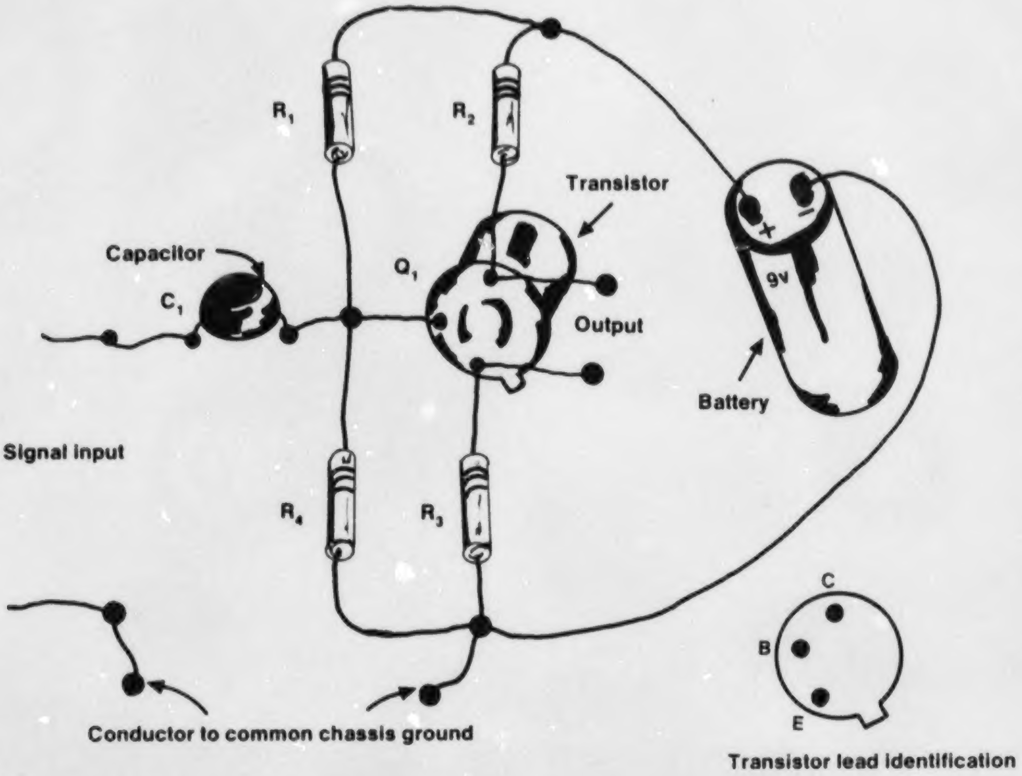
R₁
R₂
Transistor
Capacitor
C₁
Q₁
+
−
9V
Output
Battery
Signal input
R₄
R₃
C
B
E
Conductor to common chassis ground
Transistor lead identification

Fig. 2. Pictorial drawing of phase-splitter circuit

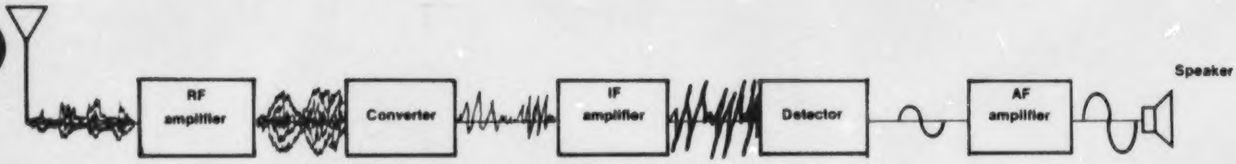

Fig. 3. Signal traced through basic radio receiver

the desired frequency that can be fed through any stage of the receiver. A technician can produce about any known frequency, modulation, and amplitude with a signal generator.

By feeding a standard signal into a circuit and observing the output with an **oscilloscope**, the service technician can tell if the circuit is operating correctly.

A **signal tracer** is basically an amplifier or, in its simplest form, just an earphone with test leads. When an earphone is used, a blocking capacitor must be placed in series with one test lead probe and the earphone. About a 1,000-ohm earphone is best to use for this purpose. Of course, since you can only hear audio signals through it, it can only be used for audio stages.

A special **commercial signal tracer** does not generate a signal but can only detect a signal that is already present in the receiver. It can amplify and reproduce a signal in any stage of the receiver. An *untuned signal tracer* can operate on a wide range of input frequencies without adjustments, but it lacks selectivity.

A special *tuned signal tracer* can be used to provide more selectivity than the regular signal tracer. The regular untuned signal tracer will pick up any radio-frequency signal that happens to be in the circuit under test. The chief advantage of the tuned signal tracer is that it can trace a particular signal at a specified frequency through a circuit.

Exercise

1. What differences can you see between the schematic drawing and the pictorial drawing regarding the locations shown for the circuit components?
2. How does the input signal waveform change as it moves from the antenna and passes through the stages of a receiver?
3. How can a signal generator be used for troubleshooting?
4. How can an oscilloscope be used?
5. How can a commercial signal tracer be used?

Section

G

Basic Television

G-1. Television Transmission and Reception
G-2. Television Tuners
G-3. Automatic Gain Control and Television Amplifiers
G-4. The Video Detector and Amplifier
G-5. The Cathode-Ray Picture Tube
G-6. Television Power Supplies
G-7. Electron Beam Deflection
G-8. Synchronization and the Sync Separator
G-9. Television Controls and Adjustments
G-10. Color Television

G-1

Television Transmission and Reception

Objectives: After completing this assignment, you should be able to—

1. discuss the modulation process used in television transmission;
2. explain the principle of persistence of vision;
3. explain how picture elements are used by a television camera to transmit a scene;
4. describe the general functions of the sections of a monochrome television receiver.

The Television Transmission System

In a television broadcasting system, the sound and the picture are transmitted together. The two carrier signals for them are spaced 4.5 megacycles apart in frequency. The sound carrier is frequency-modulated by the audio signal. The other carrier is amplitude-modulated by the picture (video) signal.

A block diagram of a basic television transmitting system is shown in figure 1. A special TV camera converts the picture content into the electrical equivalent. This is done through the use of an electron tube in the camera. At the same time, the microphone is changing any accompanying sound into the audio signal. The output from the camera is amplified and fed into monitoring apparatus. A monitoring picture tube allows the technicians to inspect the picture being transmitted for quality and content. The audio signal is monitored at the same time. The video and audio signals are amplified further and are used to modulate their respective RF carriers. The modulated output of the two signals is fed into the transmission line and a common transmitting antenna. They are transmitted at different frequencies 4.5 megacycles apart so that they will not interfere with each other.

Persistence of Vision

In your earlier school years, you learned how a series of still pictures can be shown in rapid succession. If each of these pictures, or *frames*, shows a slightly more advanced view of continuous action and is viewed in rapid sequence, you are deceived into thinking that you see motion. This is

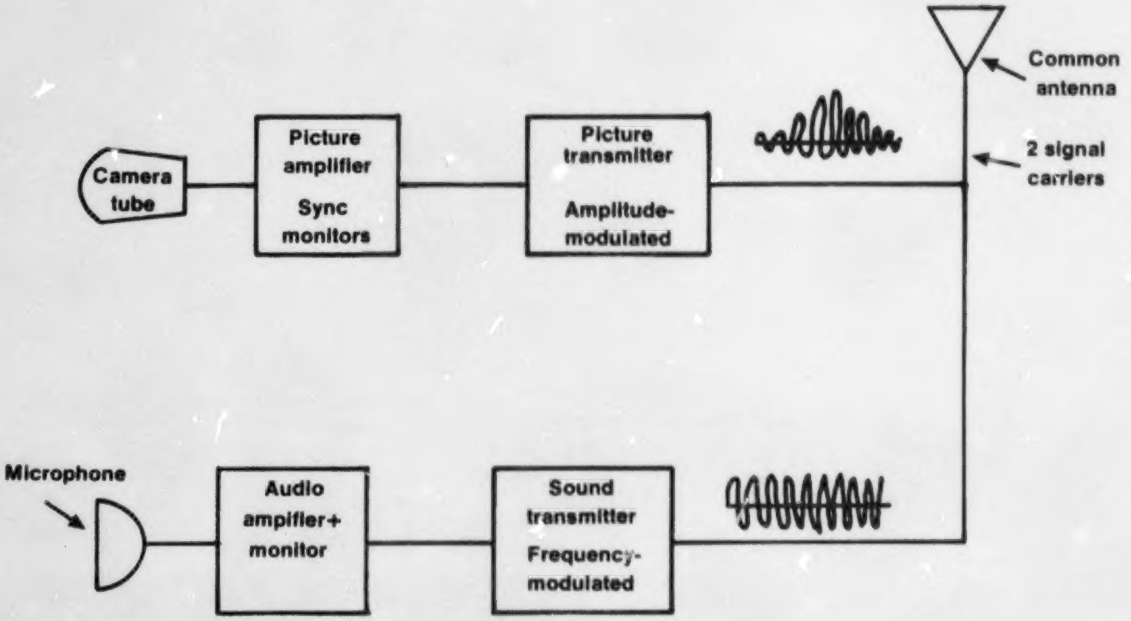

Fig. 1. Television transmitting system

called **persistence of vision**. Motion picture cameras show 24 frames per second to produce the effect of continuous motion. The eye is not able to separate the individual pictures because of its persistence of vision.

Picture Elements

Television makes use of the persistence of vision principle in the same way as the motion picture industry. However, a more complex problem of television is the transmission and reception of each separate picture. The television picture is composed of an infinite number of black-and-white dots called *picture elements*. Many of these dots vary in shade between black and white.

If you look at a newspaper photograph up close, the picture elements are quite visible. As you move away from the black-and-white photograph, you will no longer be able to see the picture elements. In this same manner, a television camera views the scene that is to be transmitted. These varying light intensities (picture elements) from black to white are focused on a photosensitive screen by means of an electron scanning beam. This photosensitive screen consists of many photoelectric cells placed very close together in the surface of the screen. A photoelectric cell is a device that can transfer light into an electrical voltage. Each cell produces a voltage that is in proportion to the light intensity striking it. These picture element voltages are amplified, fed into a modulator stage (to modulate the amplitude-modulated [AM] carrier), and transmitted to the television receivers.

Monochrome Television Receivers

The basic sections of a monochrome (black-and-white) television receiver are shown in figure 2. Conventional superheterodyne receiving circuits pick up the audio and video RF signals in the RF tuner. Both signals are amplified together in the IF amplifier section. There are usually two to four IF amplifier stages in the IF section, in order to provide sufficient amplification.

The two amplified signals are delivered to the input of the video detector, where they are demodulated. As can be seen in figure 2, there are three outputs from the video detector. One output is the sound intelligence. This output is fed into a standard superheterodyne sound section. A second output is the video intelligence. It is delivered to the video amplifier and from there to the cathode of the picture tube. The third output coming from the video detector is a series of *synchronization* (sync) *pulses* fed into the synchronization section.

From the sync section, vertical sync and horizontal sync pulses are sent into *beam deflection sections*. These synchronizing pulses are used to keep the electron scanning beam in the picture tube operating in exact step with the scanning beam of the TV camera.

A horizontal oscillator and a vertical oscillator located in the beam deflection section provide output voltages that feed into the magnetic deflection yoke. These voltages cause the vertical coil and the horizontal coil in the yoke

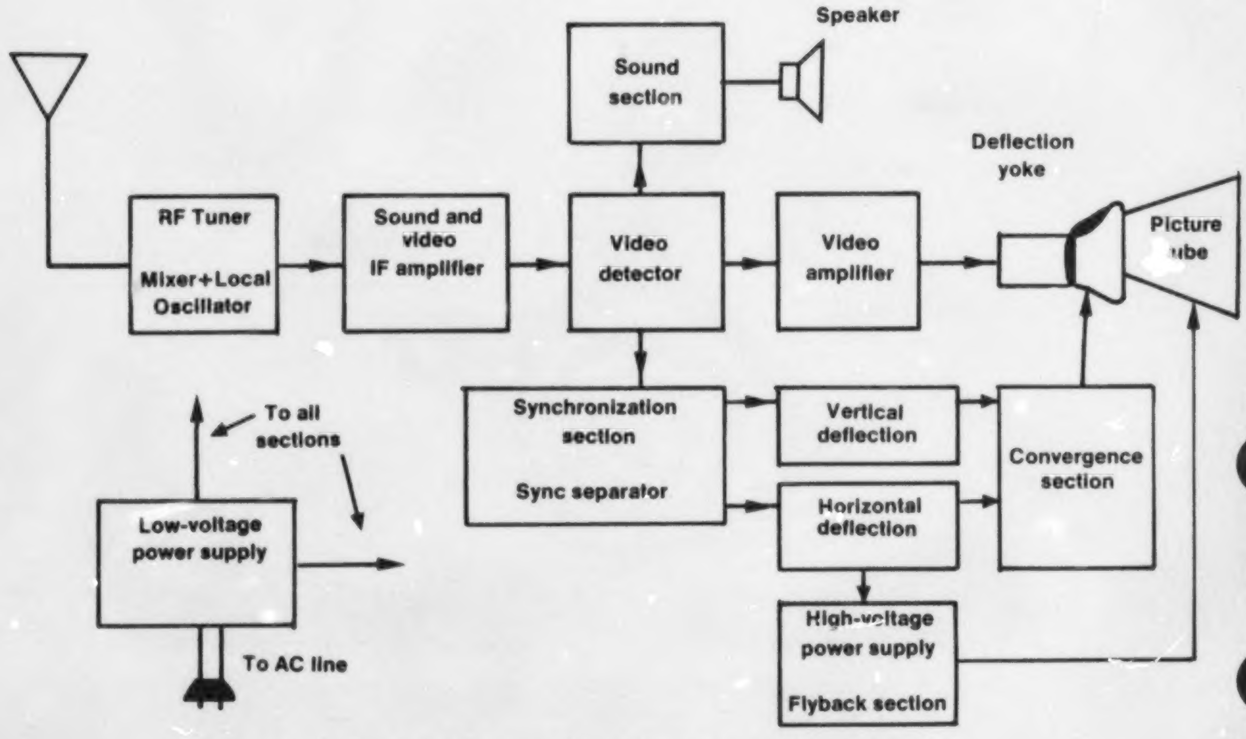
Speaker
Sound section
Deflection yoke
RF Tuner
Mixer+Local Oscillator
Sound and video IF amplifier
Video detector
Video amplifier
Picture tube
To all sections
Synchronization section
Sync separator
Vertical deflection
Horizontal deflection
Convergence section
Low-voltage power supply
High-voltage power supply
Flyback section
To AC line

Fig. 2. Block diagram of basic monochrome television receiver

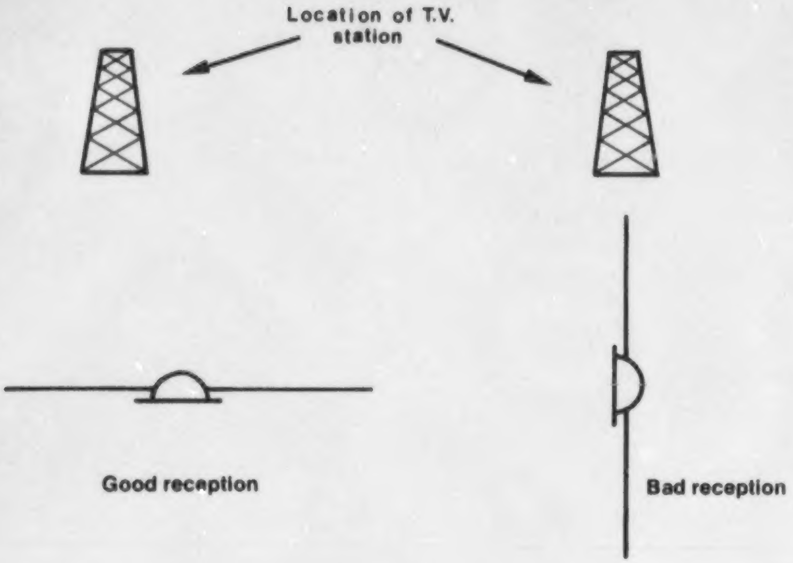

Fig. 3. Directivity of antenna for good and bad reception

to create magnetic fields. These fields cause the electron beam to scan the television screen in the proper manner.

The other output voltage coming from the beam deflection section feeds into the high-voltage section. This section has a special horizontal output transformer (flyback transformer) with a special winding coming from it that provides a high-voltage output. This output voltage is fed to the picture tube high-voltage anode, as shown in figure 2.

The remaining section of the block diagram of the monochrome television receiver—the low-voltage power supply—has outputs going to all sections of the television set. The input to the low-voltage power supply section is the AC power line cord. The output voltages coming from the low-voltage power supply are used to provide the proper bias and supply voltages to operate the entire television.

Television Receiving Antennas

There are many different types of television receiving antennas. The type that should be used depends on the particular locality and the particular design of the television set. However, one general consideration is that the impedance (given in ohms) of the antenna be very nearly the same as that of the receiver transmission line and receiver input circuit. This is so a large portion of the signal power received by the antenna will be passed on to the receiver. If the two impedances are not close, a lot of the signal would be wasted by being radiated into space.

Ghosts (the reflected images) on the transmission line may be prevented by *impedance matching* of the receiver input circuit with the transmission line. Reflected waves that are picked up by the antenna along with the desired RF signal may cause ghosts in the picture.

The proper *directivity* of the antenna may allow the antenna to be directed (aimed) toward the desired RF signal. For example, figure 3 shows how a simple rabbit-ears antenna can be directed for good reception and for poor or no reception. As can be seen, it is desirable to have the antenna directed as much as possible perfectly perpendicular to the direction the signal is coming from. The common customer complaint of ghosts on the picture can often be remedied in fringe reception areas by improving the directivity of the antenna. Increased directivity provides for an increase in gain of the amplified RF signal. This gain improves the *signal-to-noise ratio*. This ratio compares the strength of the desired input RF signal to the strength of unwanted signals. Of course, just as improved directivity can remedy the ghost problem, it may also remedy unwanted noise in the audio section.

A television receiving antenna system must be able to receive the FM sound signal, as well as the signals from very-high-frequency (VHF) and ultra-high-frequency (UHF) broadcast stations. An example of one of these outdoor-type antennas is shown in figure 4.

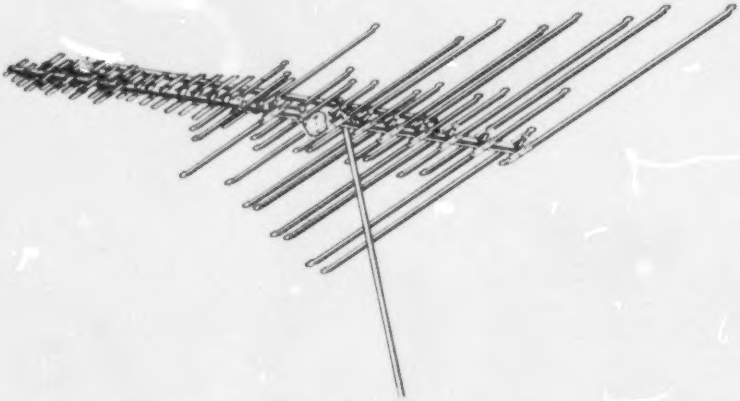

Fig. 4. Outdoor type of VHF-UHF antenna (Courtesy Winegard Co., Burlington, Iowa)

Exercise

1. How far apart in frequency are the two carrier signals when they are transmitted?
2. How can a picture be transmitted?
3. What is done with the electrical output from the TV camera?
4. What is the purpose of a video monitor?
5. What happens to the modulated output of the two signals?
6. How do motion picture cameras produce the effect of continuous motion?
7. What is a TV picture composed of?
8. What is a photoelectric cell?
9. How does the photoelectric cell produce voltage?
10. What is the general function of an RF section?
11. What happens to the incoming signals in the IF section?
12. Where are the three outputs from the video detector fed into?
13. What is the purpose of the synchronization pulses?
14. What components provide voltages to operate the magnetic deflection yoke?
15. How does the vertical and horizontal deflection coil cause the beam to scan the screen?
16. How does the picture tube high-voltage anode receive its voltage?
17. What section is connected to the AC line cord?
18. What things should be considered to decide on the type of TV antenna needed?
19. Why should the impedance of the receiver be close to that of the antenna?
20. How can ghosts be eliminated?
21. In fringe areas, how can ghosts on the picture be eliminated?
22. What improves from an increase in RF signal gain?
23. What can be learned from the signal-to-noise ratio?

108

G-2

Television Tuners

Objectives: After completing this assignment, you should be able to—

1. explain how the components of a TV tuning section operate;
2. explain the television antenna arrangement;
3. explain the difference between VHF and UHF tuners; and
4. tell how the complete television signal is transmitted.

Components of Tuners

The tuner in a television set functions in the samer manner as the tuned circuits of a radio receiver. The tuner is the first section of a television receiver. It is called the *RF section* or the *front end*. The tuning section consists of an RF amplifier, mixer, and local oscillator, as shown in the block diagram in figure 1. These three circuits operate in a television tuner in the same way as they do in the tuner of a superheterodyne radio receiver.

Modern television sets are required to amplify a wide frequency band of 6 megahertz (MHz) in width, as shown in figure 2. There is a 4.5 MHz distance between the picture carrier frequency and the sound carrier frequency.

The complete television tuner arrangement in figure 3 shows an antenna for the ultra-high-frequency (UHF) tuner and a separate antenna for the very-high-frequency (VHF) tuner. These two antennas are usually mounted together on the same mast. However, the lead wire from the UHF antenna is connected to the UHF tuner, while the wire from the VHF antenna is connected to the VHF tuner. As shown in figure 3, the dashed lines that surround the RF amplifier, mixer, and local oscillator designate the main body of the television tuner that is the VHF tuner.

The simplified version of a solid-state UHF tuner in figure 4 can be compared to the simplified schematic of a VHF tuner in figure 5 to further illustrate the difference between the two types of tuners. Besides its tuning circuits, the only electronic components in the UHF tuner are a diode mixer and the UHF oscillator. The VHF tuner has more complex tuning circuits, an RF amplifier transistor, a mixer transistor, and an oscillator transistor. All television receivers have contained both VHF and UHF tuners since 1964. A common arrangement is the turret-type tuner shown in figure 6. The UHF tuner is the rectangular box in the foreground, and the rotary VHF tuner is attached behind it. Separate tuning dials and shafts are used for each tuner.

VHF Tuners

The main functions of a VHF tuner are to select the desired channel, amplify the signal, and change the RF incoming frequency to the lower IF frequency. The incoming RF signal is changed to an intermediate frequency range of from 41.25 MHz to 45.75 MHz. Tuned circuits are found in both the RF amplifier input circuit and the output circuit. They are also located in the mixer input circuit and the oscillator circuit. All of these tuned circuits can be seen in the schematic of a VHF tuner shown in figure 5.

UHF Tuners

The customary 300-ohm antenna transmission line does not work well with UHF tuners because of a quite noticeable signal loss. A shielded twin lead cable or a round polyfoam type is re-

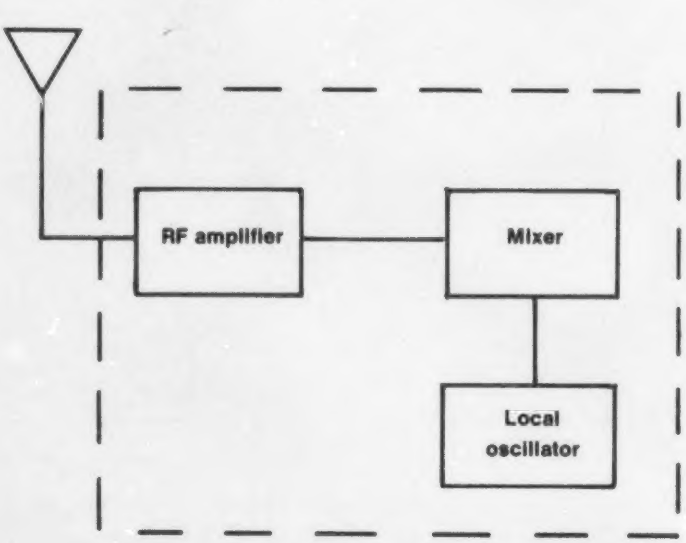

Fig. 1. RF section

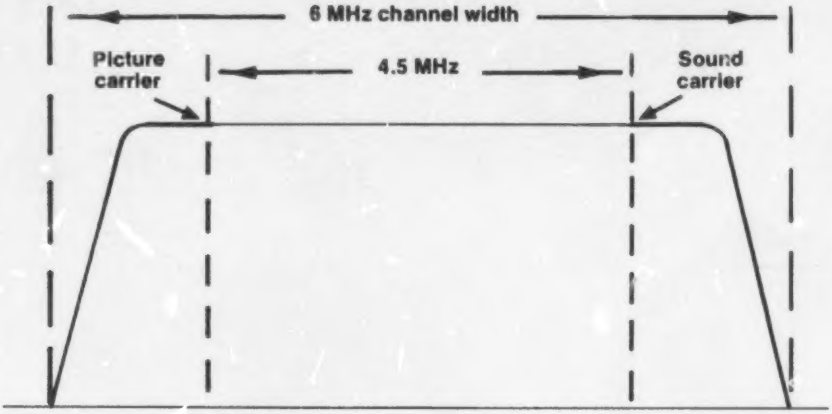
6 MHz channel width
Picture carrier
4.5 MHz
Sound carrier

Fig. 2. Frequency-response RF amplifier

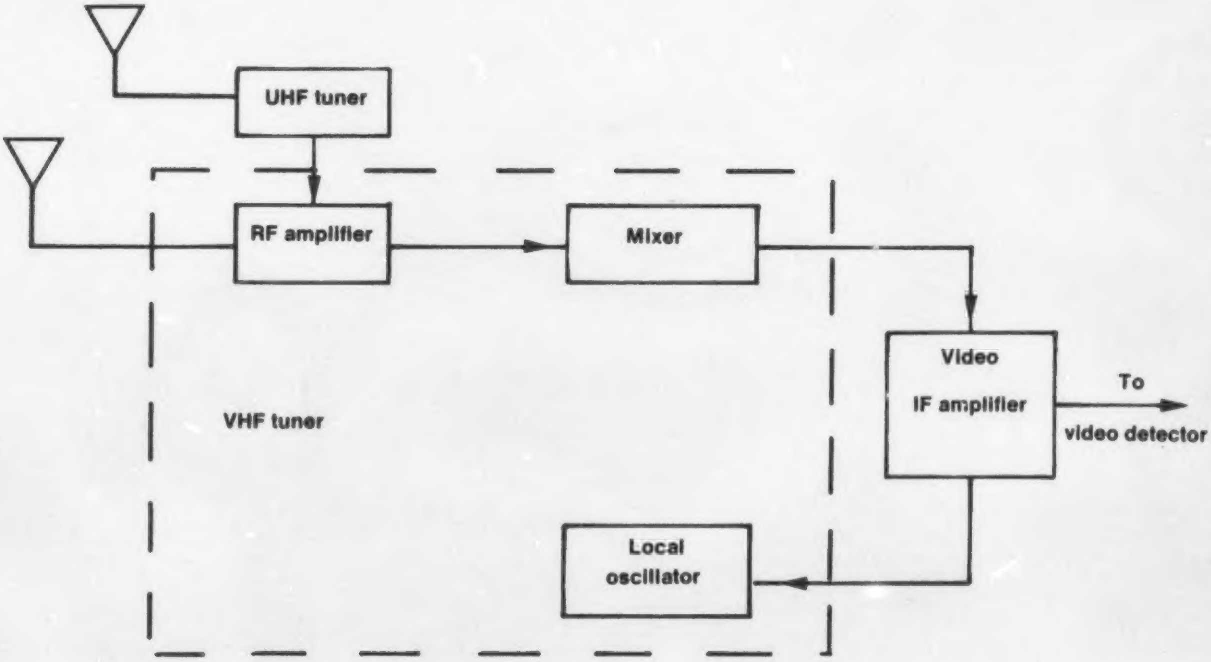
UHF tuner
RF amplifier
Mixer
Video IF amplifier
To video detector
VHF tuner
Local oscillator

Fig. 3. Typical television tuner arrangement

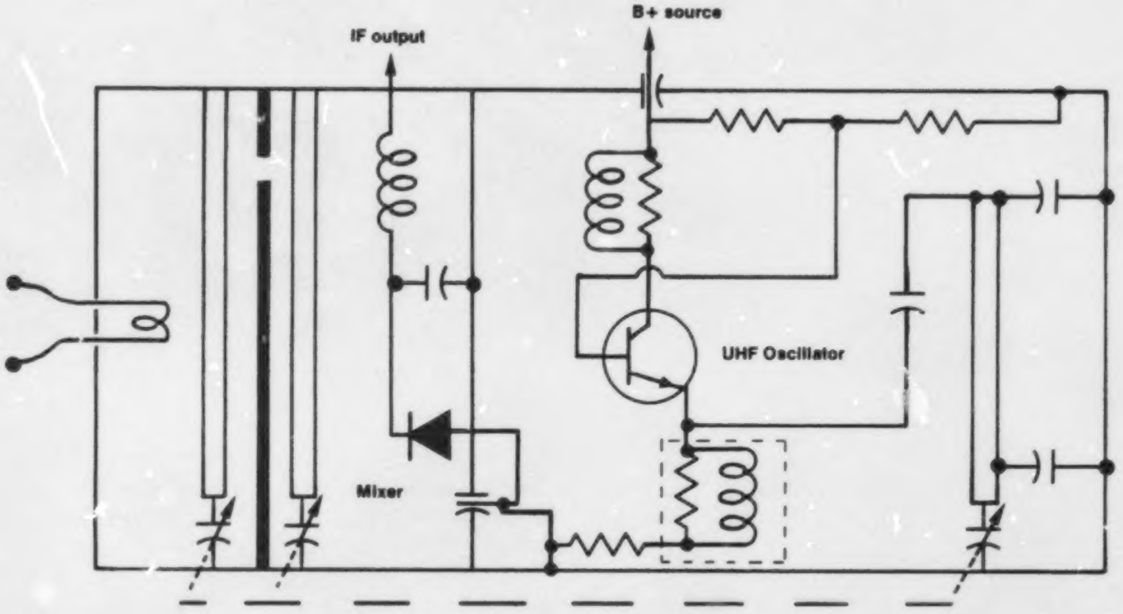
B+ source
IF output
UHF antenna terminals
UHF Oscillator
Mixer

Fig. 4. Simplified UHF tuner

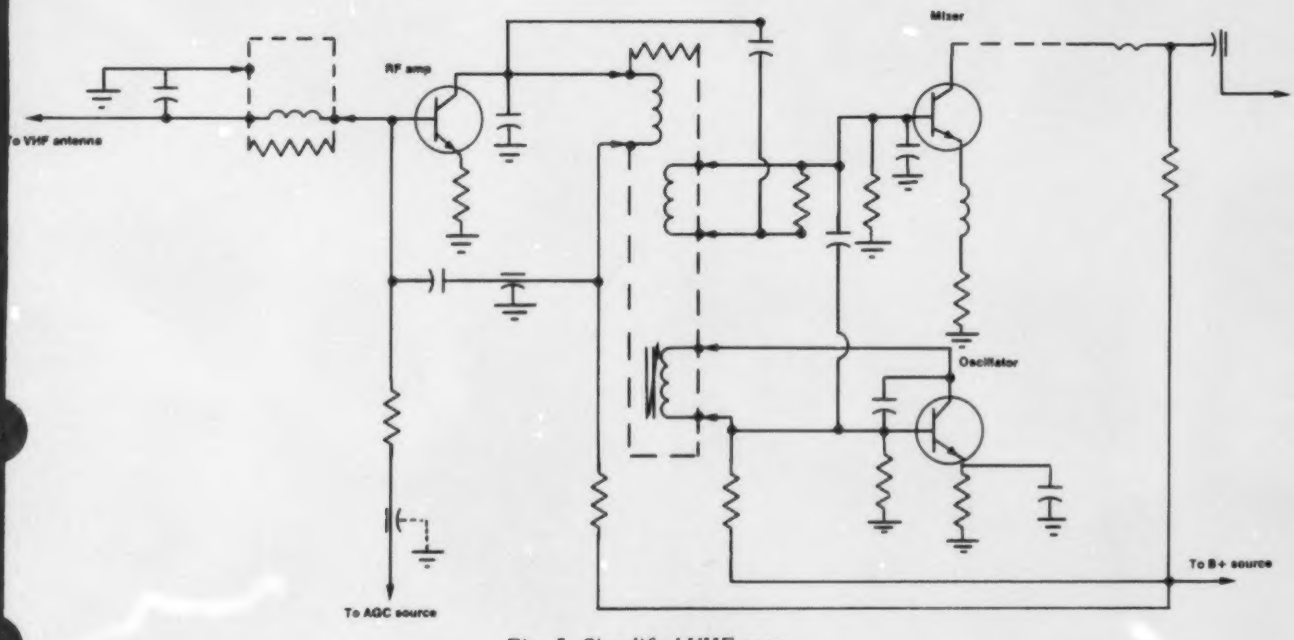
Mixer
RF amp
To VHF antenna
Oscillator
To B+ source
To AGC source

Fig. 5. Simplified VHF tuner

quired to deliver the signal from the antenna to the UHF tuner.

For a television set to be able to receive the UHF broadcast channels, the television industry had to produce a *UHF converter*. This is composed of the standard UHF tuner circuits, located in a separate cabinet. The output signal is fed from this cabinet to the VHF tuner on an unused VHF channel. The UHF converter changes the frequency of the desired UHF channel to the video intermediate frequency. The new IF frequency is produced by heterodyning the signal generated by the UHF oscillator with the video and sound carriers of the selected channel.

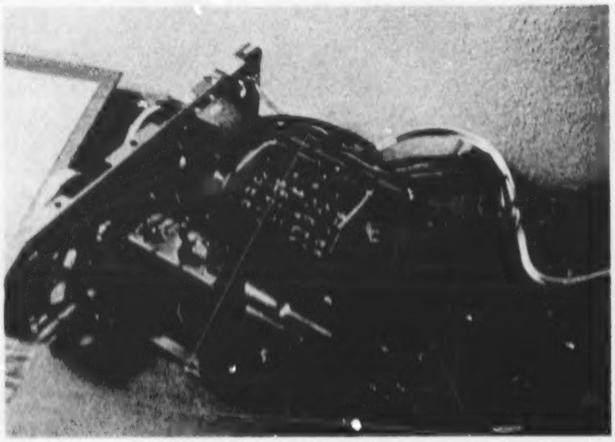

Fig. 6. VHF and UHF tuner assembly

Waveform in the RF Section

The complete television signal that is transmitted from the television broadcasting station is composed of a composite video signal and a sound signal.

The sound signal has the same type of frequency-modulated (FM) wave pattern that you learned about in the basic radio assignments.

On the other hand, the transmitted video signal must contain more than just a standard amplitude-modulated (AM) picture signal. It must also contain synchronizing pulses to keep the scanning beam in the picture tube in step with the scanning beam of the television camera.

The combination of the picture signal (video) and the synchronization pulses is called the *composite video signal*. This waveform is shown in figure 7 as it would look on an oscilloscope. You will remember from your study of radio that an oscilloscope can be connected into a circuit and will show the pattern of any waveform passing through it. This is a valuable troubleshooting technique used by radio and television service technicians.

Exercise

1. What are the stages of the RF section?
2. How are modern TV sets required to amplify frequency bands?
3. How much channel distance is there between the picture carrier frequency and the sound carrier frequency?
4. What types of tuners are required in television sets?
5. How is the transmission lead wire connected to the tuning section?
6. How are the two tuners contained in the set?
7. What are the main functions of a VHF tuner?
8. How does the incoming RF signal change in the IF section?
9. Where are tuned circuits found?
10. What type of antenna transmission line works well with a UHF tuner?
11. Where is the proper location for the UHF converter output?
12. How does the UHF converter control frequency?
13. What are the components of the composite video signal?
14. How can an oscilloscope be used to troubleshoot circuits?

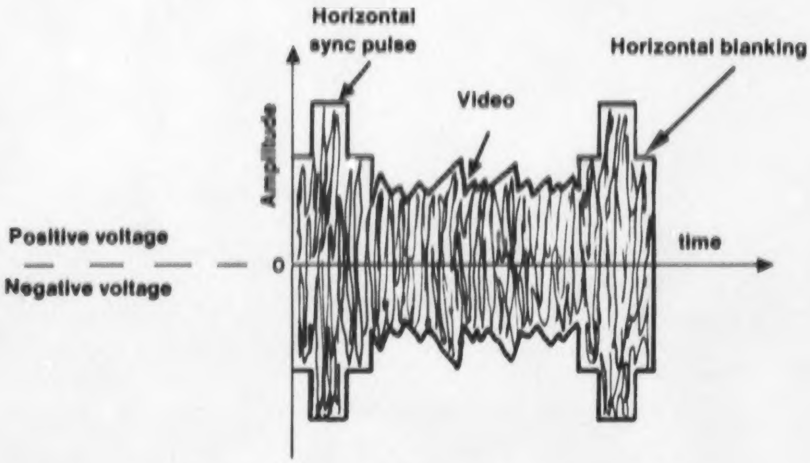

Fig. 7. The AM composite video signal in the RF section

G-3

Automatic Gain Control and Television Amplifiers

Objectives: After completing this assignment, you should be able to—

1. explain the purpose of AGC;
2. tell what the AGC keyer transistor does; and
3. explain the advantage of the IF stages.

Automatic Gain Control (AGC)

The various distances television signals have traveled, the directions from which they were transmitted, and weather conditions all affect the receiver's input signal strength. These factors vary from time to time. The result can be a loss of both sound and picture quality under varying signal level conditions. The section of the receiver that has been designed to remedy this situation is called the *automatic gain control* (AGC).

The AGC section makes continuous adjustments of the television receiver circuits. These automatic adjustments maintain a uniform picture quality regardless of any variations in signal strength. As figure 1 shows, part of the video amplifier signal is fed back to the AGC section. The transistor or vacuum tube that is used in the AGC circuit samples the signal amplitude and produces a bias voltage that is applied to the tuner's RF stage and the video IF amplifier. The gain of these stages is controlled by the bias voltage. This means that the output signal will be constant even when the input signal varies in strength.

There are several different methods of establishing an AGC system. Some receivers use a tube or transistor as an AGC amplifier. Other receivers use a combination of resistors and capacitors for AGC and do not use transistors or vacuum tubes at all in the AGC circuit. You will learn more about these different methods when you have learned the functions and interactions of all the sections of a television set.

AGC Keyer

To overcome the limitations of a regular AGC system, a *keyed AGC system* is commonly used in modern television sets. A schematic for a simplified version of an AGC keyer is shown in figure 2. The transistor Q101 samples the composite video signal pulse and produces a direct-current (DC) bias voltage. The DC bias voltage is an output voltage that is applied to the tuner's RF stage and the video IF amplifier. This bias voltage produced by the AGC keyer circuit controls the gain in the tuner and video IF amplifier sections. This in turn causes the output signal to remain constant under adverse conditions when the strength of the input signal varies.

It can be seen that diodes D-1, D-2, and D-3 prevent alternating-current

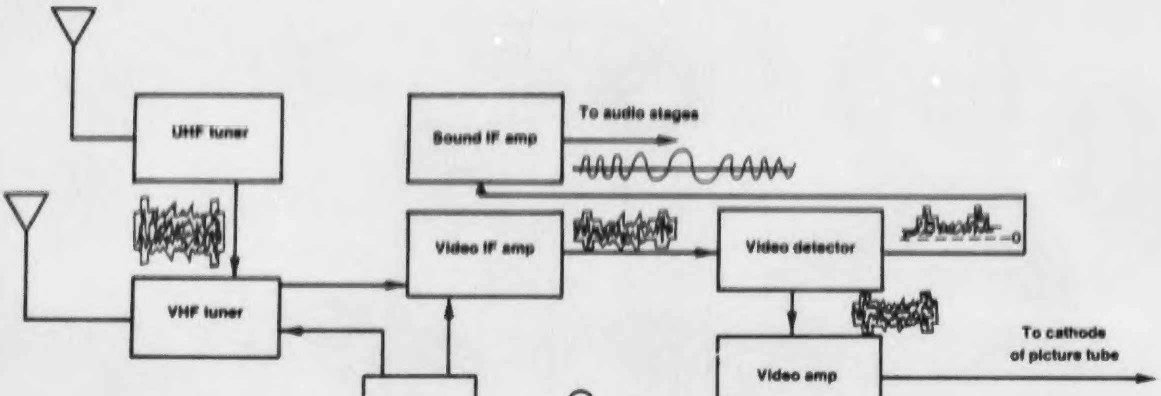

Fig. 1. Relationship of AGC and IF amplifier stages

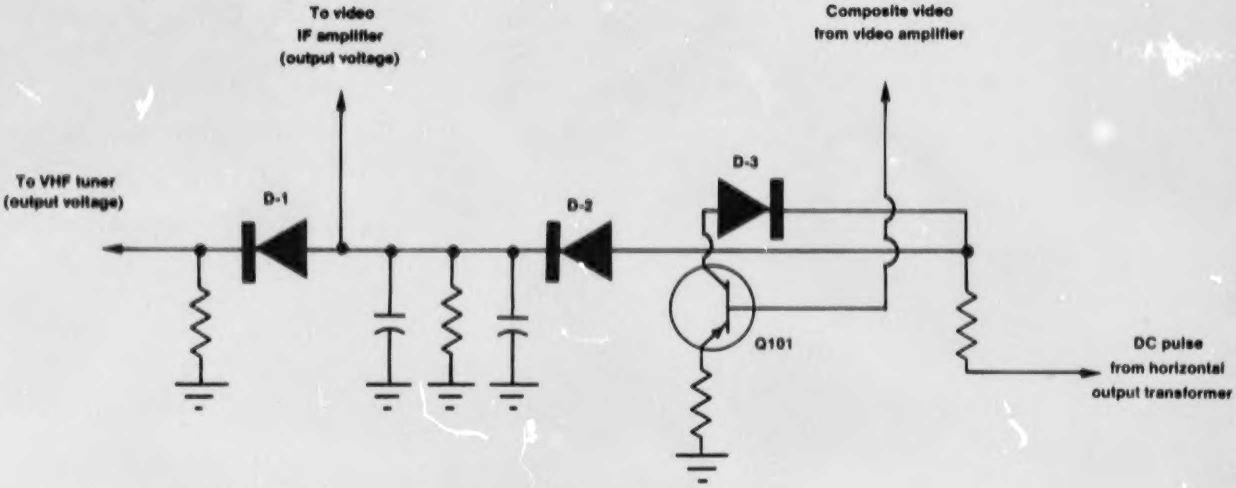
To video
IF amplifier
(output voltage)
Composite video
from video amplifier
To VHF tuner
(output voltage)
D-1
D-2
D-3
Q101
DC pulse
from horizontal
output transformer

Fig. 2. AGC keyer

(AC) components from passing through the AGC keyer system. Only DC components are present in the input and output circuits. The single lines with arrows representing these input and output lines are only one side of the line. The other line (wire conductor) connected to these other sections of the television completes these circuits by being connected to the common ground.

The input from the *horizontal output transformer* serves a particular function. A special winding on this transformer allows the DC horizontal scanning synchronization (sync) pulse to feed through D-3, transistor Q101, and then through common ground and the rest of the circuit. Remember that diodes D-1, D-2, and D-3 only conduct current in the direction against the arrows. The maximum amplitude of the horizontal sync pulse controls the amount of conduction and determines the DC voltage used for AGC.

Video IF Amplifiers

A typical IF amplifier for a TV receiver has several stages, as shown in figure 3. Superheterodyne circuits al-

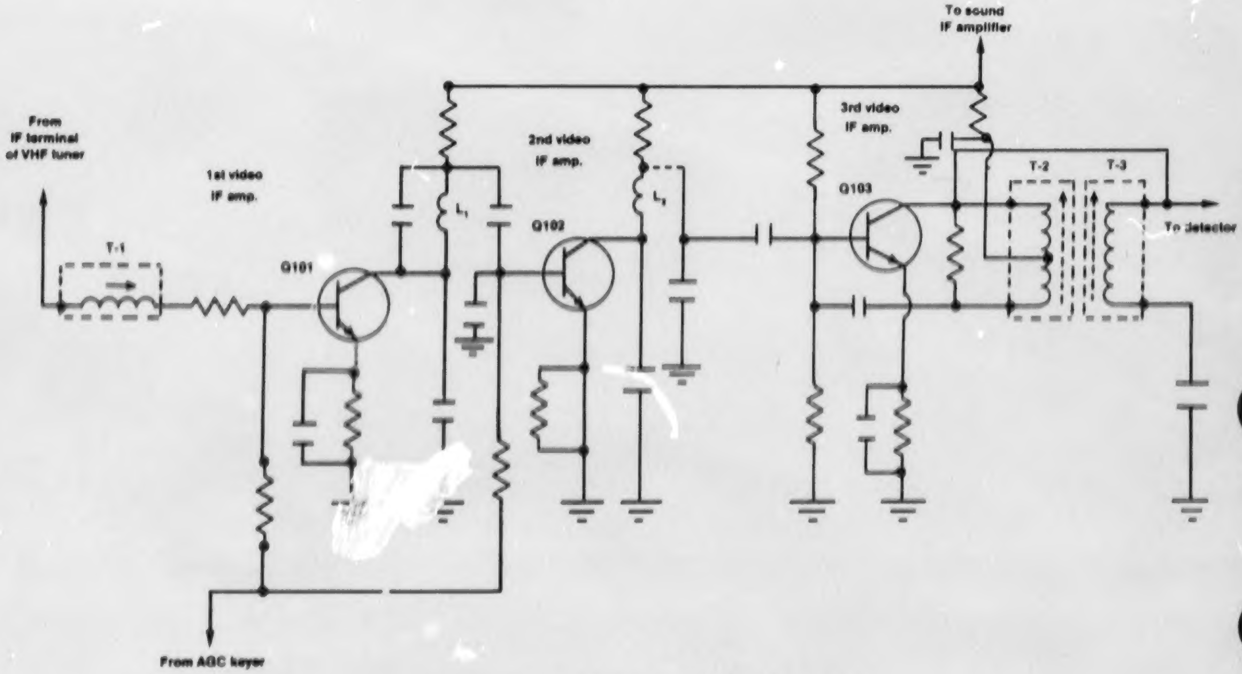
To sound
IF amplifier
From
IF terminal
of VHF tuner
1st video
IF amp.
2nd video
IF amp.
3rd video
IF amp.
T-1
Q101
L1
Q102
L1
Q103
T-2
T-3
To detector
From AGC keyer

Fig. 3. Three-stage video IF amplifier

low operation of television sets at lower frequencies than the incoming high-frequency signals. The VHF mixer stage output has been reduced to the intermediate frequency and is fed to the base of transistor Q101. This lower frequency provides the receiver's amplifiers with better selectivity, stability, and higher gain that would be possible with an RF incoming signal.

The composite video signal is delivered from the collector of each transistor to the base of the succeeding stage, where it is amplified in the same manner as a radio signal. Transformers T-2 and T-3 are used to provide transformer coupling between the third video IF amplifier stage and the video detector.

The way that resistors, capacitors, coils, transformers, and other circuit components are used in TV circuits depends on the way they have been designed. However, the common elements of circuits are used generally for the same purposes. Resistors are used to establish correct transistor bias voltages at the emitter base and collector. They are used for resistance coupling and as load resistors. Capacitors are used not only for tuned tank circuits and oscillators but also for coupling and as bypass capacitors. Both coils and capacitors are used as filters. For example, coils L_1 and L_2 are used as filter traps in the circuit shown in figure 3.

Unwanted signals that are near the frequency of the channel the receiver is tuned to may sometimes be able to pass through the RF tuned circuits. When this happens, they will be fed into the video IF amplifier. For this reason, the design of many television receivers has included trap circuits in the video IF amplifier. These unwanted signals must be suppressed before they reach the video detector and are fed through the video amplifier to the cathode of the picture tube. If this were the case, the quality of the picture would definitely suffer a loss, and it would be too late to remedy the situation.

Exercise

1. How can weather conditions affect the TV receiver?
2. What is the function of AGC?
3. What are two methods of establishing an AGC system?
4. What is the purpose of the AGC transistor producing a DC bias voltage?
5. What does the AGC bias voltage control?
6. How does controlling the gain in the tuner and video IF sections work to advantage?
7. How is alternating current prevented from passing through the AGC?
8. How do the diodes in the AGC circuit conduct current?
9. What determines the value of the DC voltage used for AGC?
10. How is the composite video signal fed from one transistor stage to another?
11. What kind of coupling is provided between the last video IF stage and the video detector?
12. How are resistors usually used in TV circuits?
13. How are capacitors used in TV circuits?
14. Why have filter trap circuits been included in the video IF amplifier of many receivers?

G-4

The Video Detector and Amplifier

Objectives: After completing this assignment, you should be able to—

1. explain how the composite video signal changes in the video detector;
2. explain why the electronic circuits in a TV should be understood even though television sets now being manufactured use integrated circuits (ICs); and
3. explain the function of the video amplifier.

Video Detector and Amplifier Circuits

Detection in television receivers is a process that is concerned with the demodulation of both the sound and the video portions of the input signal. Since sound detectors were covered in the basic radio assignments, the sound takeoff points will be mentioned but it will not be necessary to examine these sound circuits.

The video detector is fed by the last IF amplifier stage in the video IF amplifier. The sound detector in radio circuits was also fed by the last IF amplifier stage. The same sort of superheterodyne circuits found in the basic radio circuits are also found in the video detector.

The composite video signal is fed into the input of the video detector from the video IF amplifier, as shown in figure 1. Only the positive half of the composite video signal envelope is produced at the detector output, after it has been rectified and filtered. This video envelope is sent on to the video amplifier for further amplification.

The frequency-modulated (FM) sound signal is fed into the sound section where it goes through the process of IF amplification, detection, and audio amplification. The sound amplifiers in most recent television sets are integrated circuits (ICs). The symbol for an IC amplifier is a triangle, as shown in figure 2.

Although the detector circuit shown in figure 1 is more often in the form of a small integrated circuit like the one shown in figure 3, it is important to understand the arrangement of components and their function inside the IC. For this reason, manufacturers always supply a schematic, like the one in figure 1, to go along with the IC drawing showing the external connections, like the one in figure 3. Even though present-day radio and television sets almost always contain ICs or modules that are replaced to repair a faulty stage, you must still understand the operation of each stage.

Electronic Modules and ICs

The electronic module was a complete circuit like the more recent integrated circuit, but it could not be designed as

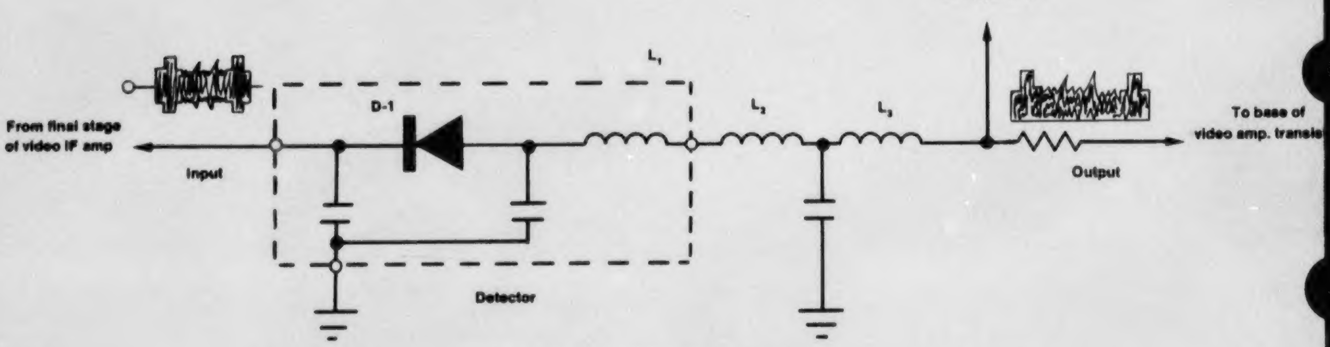
To sound strip
L₁
D-1
L₂
L₃
From final stage of video IF amp
Input
Output
To base of video amp. transis
Detector

Fig. 1. Video detector stage

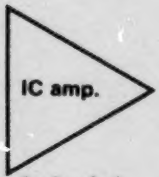

Fig. 2. Symbol for IC amplifier

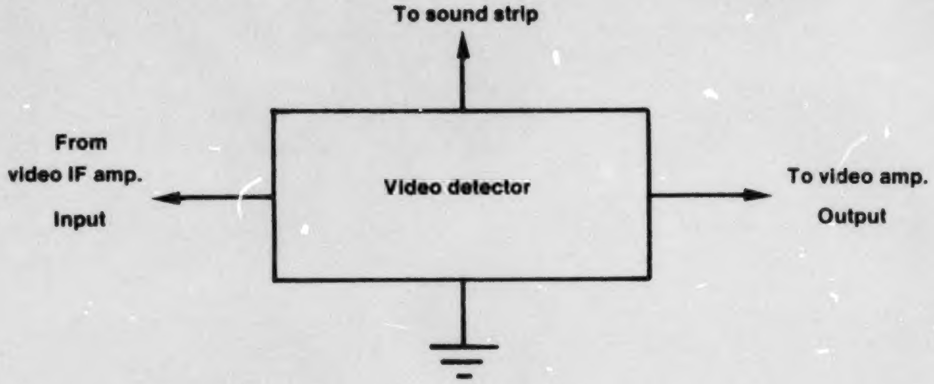
To sound strip
From
video IF amp.
Input
Video detector
To video amp.
Output

Fig. 3. Symbol for IC detector

small as the IC. The first modules were huge vacuum tube circuits. Their only advantage was to speed up repair jobs by allowing defective stages to be replaced in a hurry and repairs done later. Transistorized modules and printed circuit techniques greatly reduced the size of the modules and made them more practical. Many of these modules are still used in radio and television sets.

The first IC that was used in radios and televisions was a detector because of the simplicity of this type of circuit. An IC is actually a microminiature module. All of its components and interconnections are fabricated. Appropriate areas of a single-crystal semiconductor chip are given special processing to produce an IC. A doped silicon chip or wafer has electronic components placed into it by a diffusion process. Metallic contact points are attached to the surface of the chip

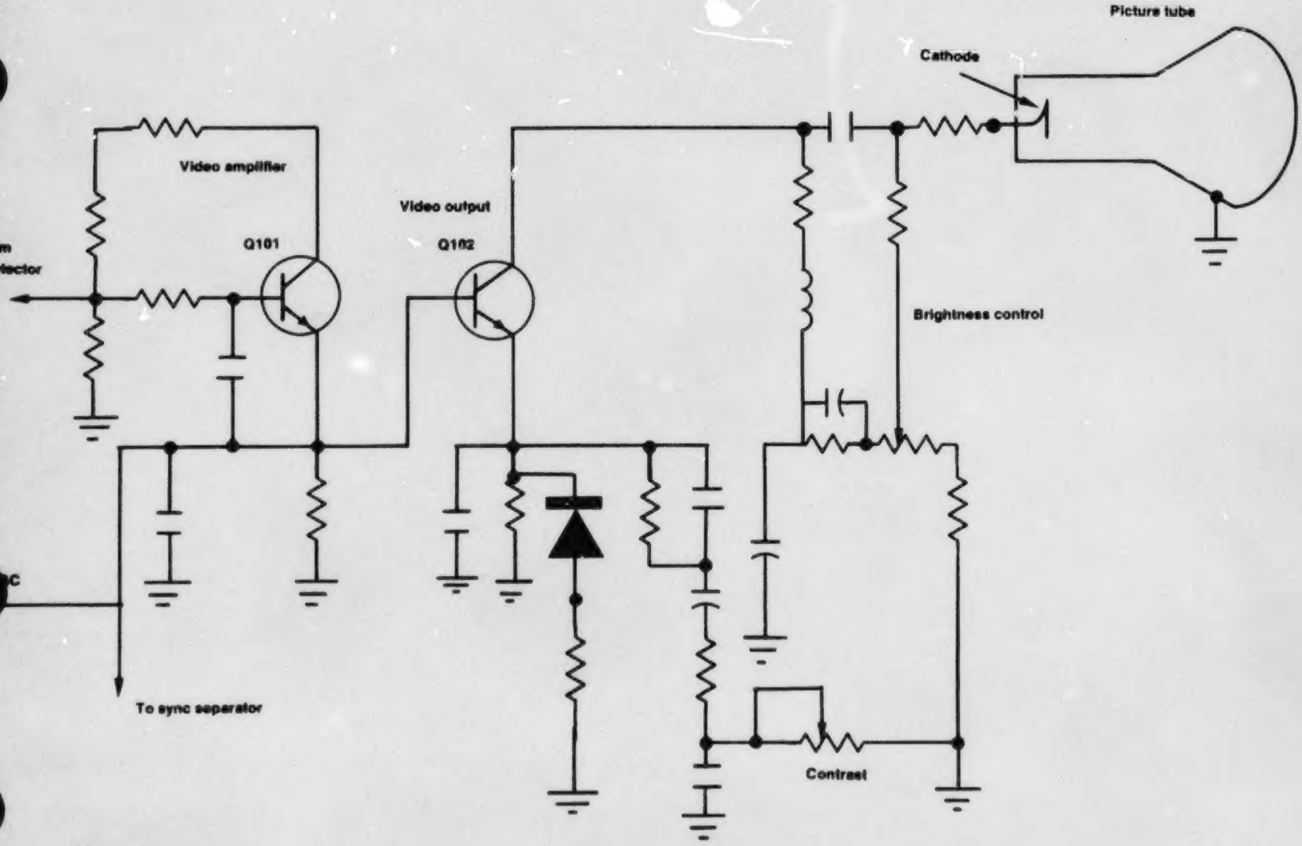
Picture tube
Cathode
Video amplifier
Video output
rom
detector
Q101
Q102
Brightness control
C
To sync separator
Contrast

Fig. 4. Video amplifier

to provide transistor bias voltages, as well as input and output terminals.

The Video Amplifier

The stage between the video detector and the cathode of the picture tube is called the video amplifier. As the name implies, its function is to amplify the output of the video detector a sufficient amount so that it can modulate the picture tube. The picture tube bias is varied by the detector output, and the bias causes the light output of the picture tube to vary in step with it.

The video amplifier provides voltage amplification of from 40 to 80 times the output voltage from the video detector. This provides enough voltage to modulate the cathode-ray picture tube.

The video amplifier shown in figure 4 uses transistors Q101 and Q102 as amplifiers. The input video signal from the detector is applied to the base of Q101. Here it is amplified and sent on to the base of Q102 for further amplification. This *video output* transistor feeds to the cathode from its highly amplified collector output. The brightness and contrast picture tube controls are also placed in the video output circuit.

Two other outputs from the video amplifier are fed to the AGC and sync separator circuits. The function of the AGC circuit has already been covered. The sync circuit will be studied in a later assignment.

Exercise

1. In a TV receiver, what process is detection concerned with?
2. Where does the video detector feed its outputs?
3. What stage feeds the composite video signal to the video detector?
4. What symbol is used for an IC amplifier?
5. How can you understand what is in an IC when all you see of it are its input and output terminals?
6. What was the forerunner of the IC?
7. What is the advantage of the IC over the electronic module?
8. Why was the detector circuit used for the first integrated circuit to be produced?
9. What is the stage between the video detector and the picture tube cathode?
10. How much voltage amplification is provided by the video amplifier?
11. Where are the brightness and contrast controls placed?

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Objectives: After completing this assignment, you should be able to—

1. discuss the oscilloscope CRT and the television CRT;
2. name the main parts of a television picture tube; and
3. explain how the electrons flow through the picture tube.

G-5

The Cathode-Ray Picture Tube

The television picture tube is a special type of cathode-ray vacuum tube. You learned earlier that vacuum tubes have had as much air as possible pumped out of them to create a vacuum. Review Assignment B-2 on electronic safety if you need to handle picture tubes. It is especially important to carry them properly because if one breaks, it *implodes*. This is as dangerous as an explosion.

A **cathode-ray tube** is an electronic device capable of converting an electrical signal (voltage) into a visual one. The electron tubes you learned about from a previous assignment used the amount and intensity of the electron stream flowing from the cathode to the plate to produce plate current. The cathode-ray tube (CRT) differs from them in that it is concerned with the

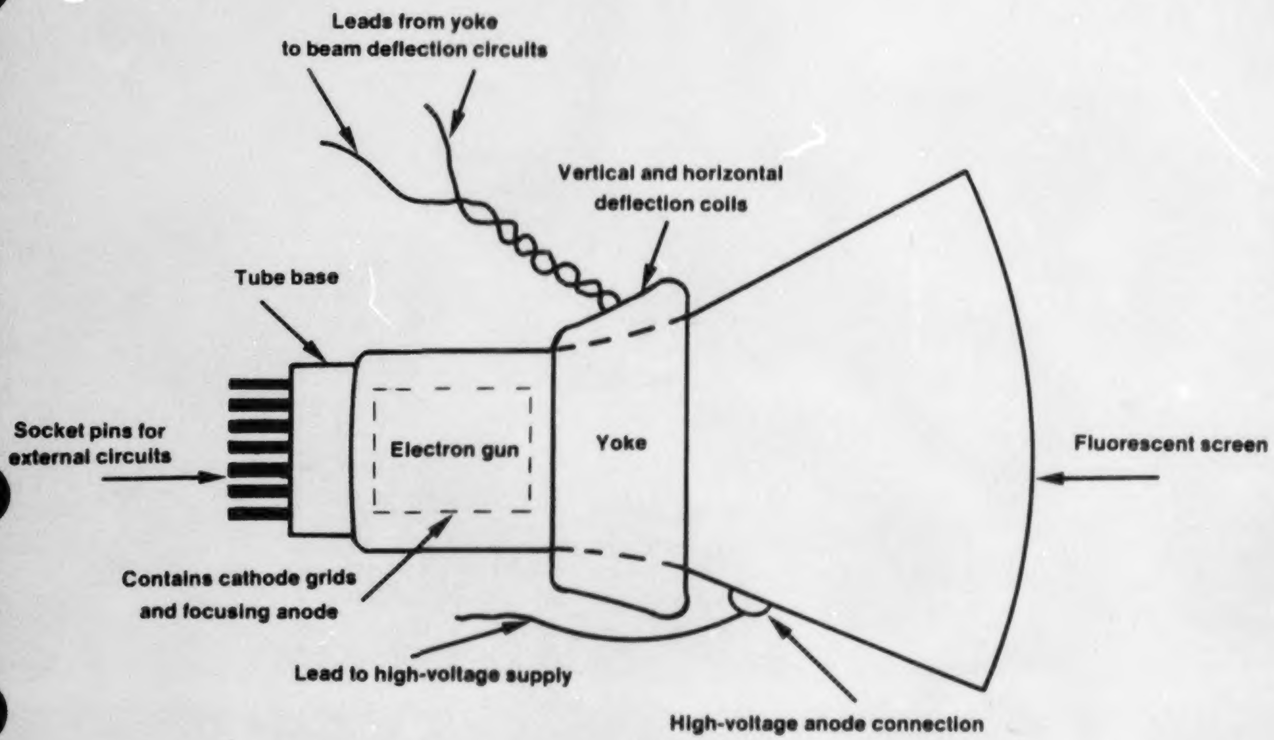
Leads from yoke to beam deflection circuits
Vertical and horizontal deflection coils
Tube base
Socket pins for external circuits
Electron gun
Yoke
Fluorescent screen
Contains cathode grids and focusing anode
Lead to high-voltage supply
High-voltage anode connection

Fig. 1. Television picture tube

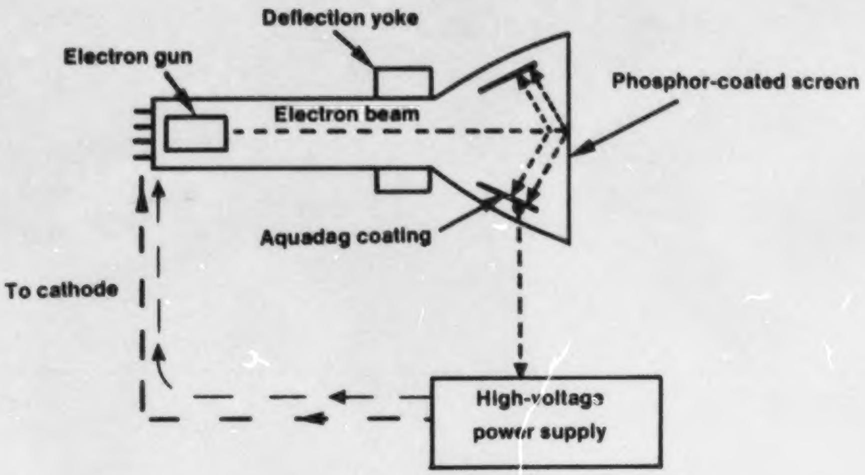
Deflection yoke
Electron gun
Phosphor-coated screen
Electron beam
Aquadag coating
To cathode
High-voltage power supply

Fig. 2. Electron flow in the picture tube

direction of the electron stream and its intensity.

The Oscilloscope CRT

An oscilloscope uses a cathode-ray tube that guides the direction of the electron stream or beam by means of electrostatic deflection plates. These vertical and horizontal deflection plates are contained within the tube. In the case of the CRT used in an oscilloscope, a visual display of waveforms is presented on its screen. Graph lines on the surface of the screen allow the viewer to measure the amplitude of waves to determine the amounts of currents and voltages.

The Television CRT

The difference between the oscilloscope CRT and the television CRT is that the television CRT uses *magnetic deflection* in the picture tube instead of electrostatic deflection. Basically, both tubes function in the same manner.

Three main components are necessary for the tube to function properly. These are an electron gun, a deflection system, and a fluorescent screen, as shown in figure 1.

The electron gun is designed to focus the electrons emitted from it into a steady stream striking the phosphor-coated screen, as shown in figure 2. Figure 1 represents the general arrangement and physical appearance of a TV picture tube, while figure 2 shows the path of electron flow through the picture tube. If it were not for the beam deflection yoke, the electron beam would strike only the center of the screen as shown.

As you learned earlier, the beam actually *scans* the screen as your eyes would scan the page of a book starting at the top left corner. It moves one line at a time from left to right and from top to bottom. Wherever the beam strikes the phosphor-coated screen, secondary electrons bounce off of the screen and are attracted to the *Aquadag-coated* plates as shown. This Aquadag mate-

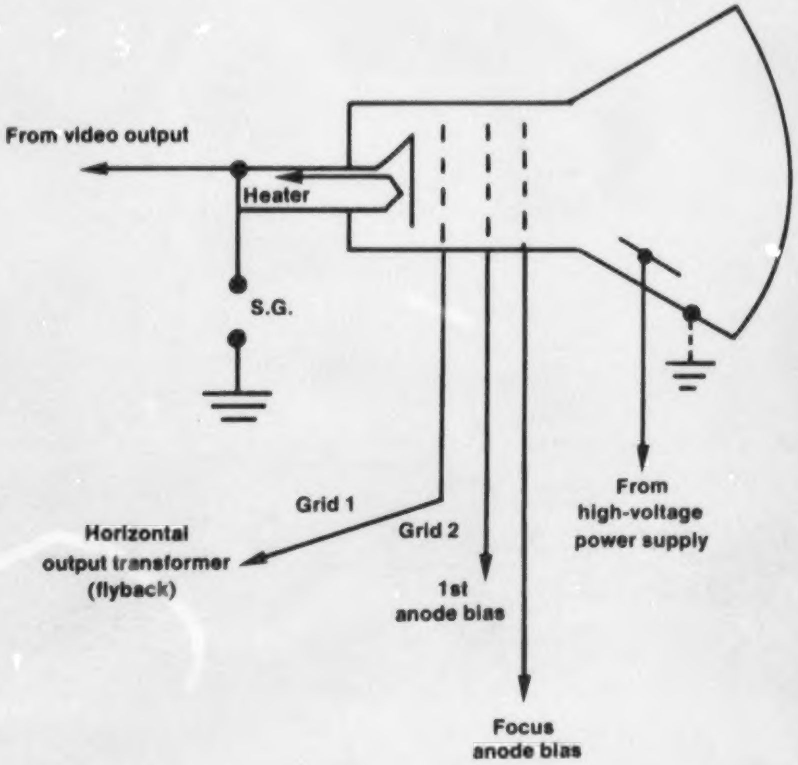
From video output
Heater
S.G.
Grid 1
Grid 2
Horizontal output transformer (flyback)
1st anode bias
Focus anode bias
From high-voltage power supply

Fig. 3. External connections to the picture tube

rial has a more positive potential than the cathode and grids in the electron gun. This causes the electron current (i) flow to proceed from the Aquadag anode, through the high-voltage power supply, to the cathode, and back again to strike the screen. This is the direct-current (DC) circuit of the electrons flowing through the picture tube.

The external connections to a typical black-and-white picture tube are shown in figure 3. The video information is fed from the video output circuit to the cathode. The heater element from the low-voltage power supply heats the cathode and causes the emission of electrons as in any electron tube. A spark gap (S.G.) is provided as a safety precaution against stray high voltages. These high voltages would be picked up and diverted to ground. The other internal elements of the picture tube receive their bias voltages from external circuits.

Exercise

1. How is a cathode-ray tube produced?
2. What is a cathode-ray tube?
3. How does the CRT differ from other vacuum tubes?
4. Where are the vertical and horizontal deflection plates of an oscilloscope CRT located?
5. How can the CRT in an oscilloscope be used?
6. What is the purpose of the electron gun?
7. What component causes the electron beam to move instead of striking only the center of the screen?
8. Where is the deflection yoke located in the TV set?
9. How does the beam scan the screen?
10. What causes the cathode to emit electrons?
11. Why is a spark gap provided?

G-6

Television Power Supplies

Objectives: After completing this assignment, you should be able to—

1. name the three main stages of a power supply;
2. explain the function of a half-wave rectifier;
3. discuss the full-wave rectifier and the bridge rectifier; and
4. define a low-voltage and a high-voltage power supply.

The heart of any television set is its power supply. Its function is to deliver the required voltages and current to all sections of the set in the same manner that our heart pumps blood to all parts of our body. A power supply has three main sections or stages. These are the input stage, the conversion stage, and the output stage, as shown in figure 1.

Television Low-Voltage Power Supply

A simple transformerless power supply schematic for a transistorized low-voltage TV power supply is shown in figure 2. All of the necessary components of the input circuit are shown within the dashed lines. It contains an AC line plug to couple the AC line voltage into the power supply, an overload protection, and an on-off switch. The circuit overload protection may be in the form of a fuse, as shown in figure 2, or it may be a special circuit breaker.

The conversion stage consists merely of the diode rectifier D-1 and a very simple filtering circuit. Remember the AC line current will only flow through diode D-1 in a direction against the arrow from cathode to anode. When the switch is on, current flows through D-1 and the high side of the circuit to the low (grounded) side of the circuit. Therefore, the conversion stage changes the AC line current to a pulsating direct current. This pulsating direct current is filtered and appears in the output stage as a usable form of direct current.

The output voltages used mostly for transistor bias voltages are designated by the arrows and circled numbers 1, 2, 3, and 4 (see fig. 2). These same numbers terminating at an arrow are shown at other points in various TV sections to designate their connection to the power supply output. The actual voltages present at these numbered points in the power supply output are also included in the manufacturer's data or on the schematic. The resistors shown in the output stage act as voltage dividers to provide the desired values of DC output voltage at each of the four output points.

A transformer-type input circuit is shown in figure 3. In this circuit, the primary coil of the transformer is included in the AC input circuit. The secondary windings are in the conversion stage. From the transformer secondary, a method of diode rectification is added and an output stage as in figure 2.

Power supplies that use a power tranformer in the input stage may use any one of several different types of rectifiers. A **half-wave rectifier** uses only one diode, as shown in figure 4. The diode must be forward-biased for current to flow through it. The cathode must be at a negative potential with respect to the anode for current to flow. When the polarity at the secondary of the transformer is as shown in figure 4, the diode is forward-biased and current (i) flows on the negative half cycle as shown. When the AC current changes direction and swings positive, the anode will be reserve-biased and current will not flow. The output is one-half of the wave—thus, the name half-wave rectifier.

A **full-wave rectifier** conducts current during both half cycles of the alternating-current wave. It uses two diodes, as shown in figure 5. This circuit is a full-wave rectifier producing a

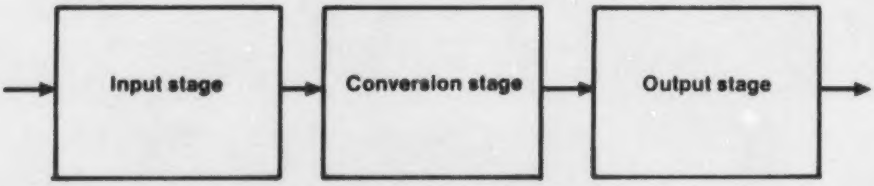

Fig. 1. Main stages of TV power supply

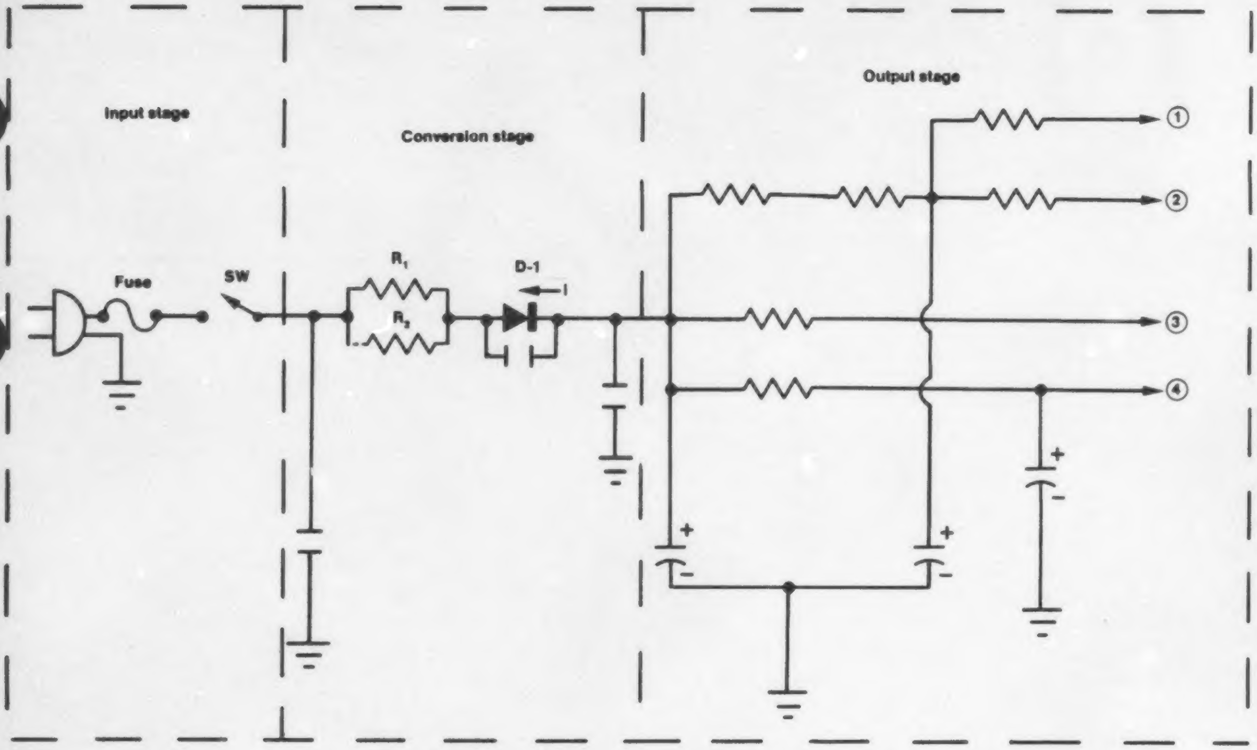
Input stage
Conversion stage
Output stage
Fuse
SW
R1
R2
D-1
I
①
②
③
④
+
–
+
–
+
–

Fig. 2. Low-voltage television power supply

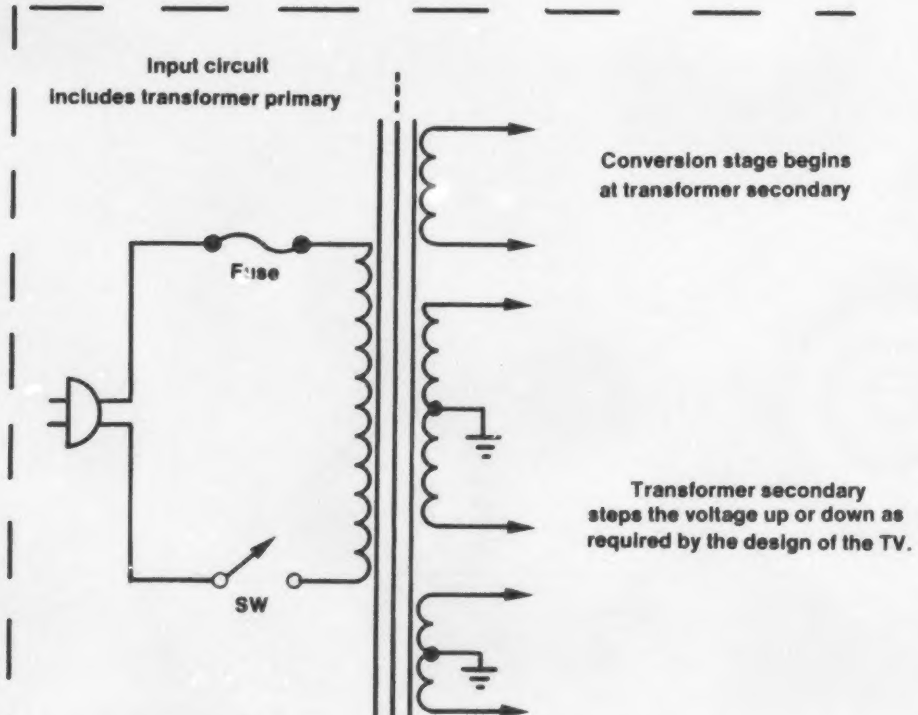
Input circuit
includes transformer primary
Fuse
SW
Conversion stage begins
at transformer secondary
Transformer secondary
steps the voltage up or down as
required by the design of the TV.

Fig. 3. Transformer-type power supply input

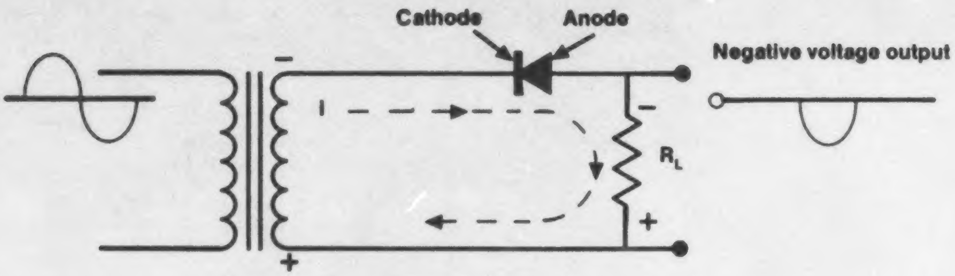

Fig. 4. Half-wave rectifier circuit

negative DC output. The center-tapped transformer allows two half-wave rectifiers to feed the same load resistor R_L. On the negative alternation of the AC wave, D_2 conducts and the current (i) flows as shown. The output is a negative half cycle. When the AC current changes direction and swings positive, as shown in figure 6, D_2 will no longer conduct because it is reverse-biased. The cathode of D_1 is now more negative than its anode (forward-biased), and so it conducts on the second half cycle. The output is another negative-going half cycle, as shown in figure 6. To change this negative DC supply to a positive DC source, it is only necessary to reverse the directions of diodes D_1 and D_2. You can see that this would cause the current to flow in the opposite direction.

The most commonly used rectifier is called a **bridge rectifier**. Four diodes are used in the arrangement shown in figure 7. Even though the AC line voltage changes polarity, the voltage output from the bridge rectifier will always be of the same polarity. The arrangement of the diodes is the key to the operation of the bridge rectifier. At any particular instant, only two of the diodes will be conducting current. The other two diodes will block the flow of current. If the top of the transformer in figure 7 has a negative polarity at its secondary coil and a positive polarity at the bottom of the secondary, only one path is provided for current flow. On this first half cycle, only diode D_1 and diode D_4 will conduct current. Current flows as shown by the dotted lines. Notice that the direction of current through the load resistor R_L is from bottom to top, so the top of R_L must be more positive with respect to the bottom.

Figure 8 illustrates the circuit diode action when the top of the transformer

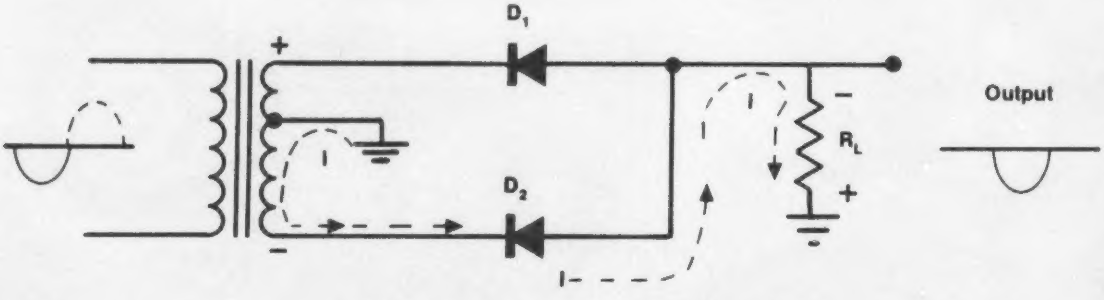

Fig. 5. Full-wave rectifier (first half cycle)

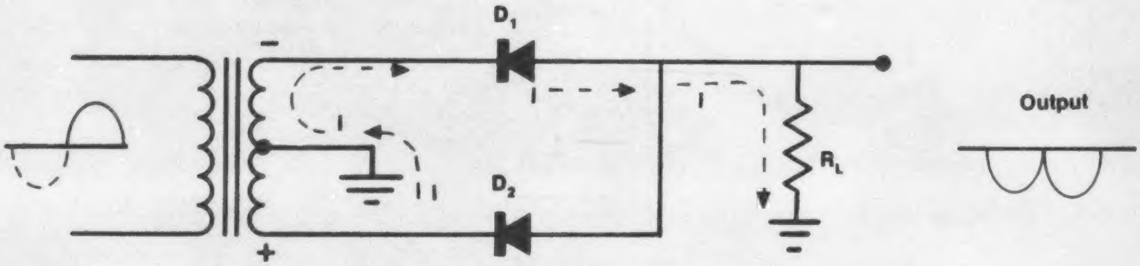

Fig. 6. Full-wave rectifier (second half cycle)

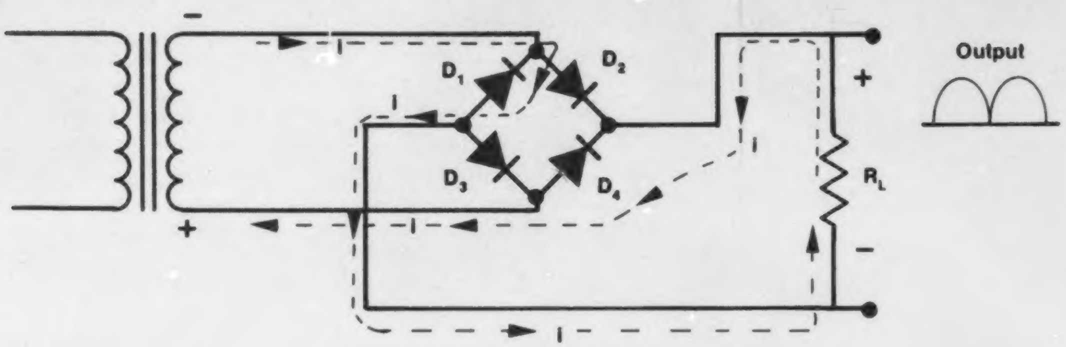
-
+
i
i
i
i
i
D1
D2
D3
D4
Output
+
R_L
-

Fig. 7. Bridge rectifier (first half cycle)

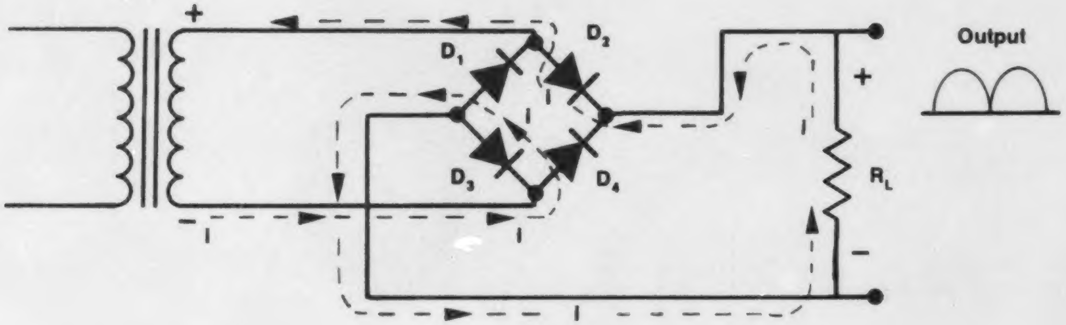
+
-
i
i
i
i
i
D1
D2
D3
D4
Output
+
R_L
-

Fig. 8. Bridge rectifier (second half cycle)

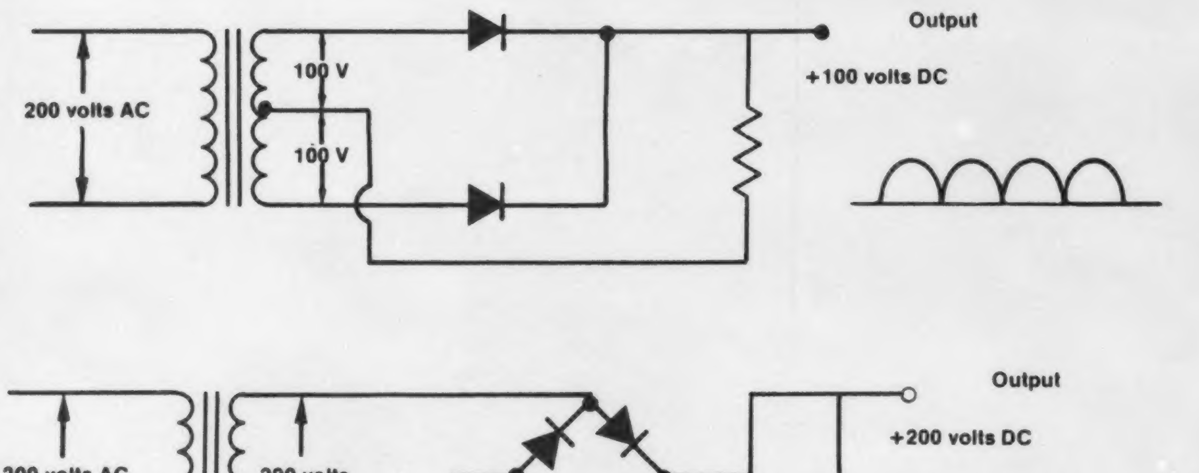
200 volts AC
100 V
100 V
Output
+100 volts DC
200 volts AC
200 volts
Output
+200 volts DC

Fig. 9. Comparison of full-wave rectifier and bridge rectifier

secondary becomes positive and the bottom becomes negative. On this next half cycle, diodes D_2 and D_3 conduct current while D_1 and D_4 block the current. The path of current flow is shown by the dotted lines. Although current through the bridge flows differently in figure 7 and figure 8, the direction of the current is the same through R_L in both instances.

If you compare the two rectifier circuits in figure 9, you will see that both circuits use the same transformer and the same primary voltage. The only difference is that the transformer of the full-wave circuit is center-tapped. Only one diode at a time passes current in the full-wave circuit. Only one-half of the secondary voltage goes to each diode. This produces an output voltage that is one-half of the 200-volt peak input voltage. The result is a positive-going voltage of 100 volts in the output.

The two diodes passing current in the bridge circuit are always connected across the entire secondary coil of the transformer. The output voltage is 200 volts, which is equal to the input voltage.

High-Voltage Power Supply

By definition, the difference between a low-voltage supply and a high-voltage supply is that the high-voltage one supplies *more than 300 volts* to operate the particular electronic equipment it was designed for. A low-voltage supply is used to power electronic components that require less than 300 volts for their operation.

The high-voltage power source in a television is located in the horizontal deflection circuit. A high-voltage winding from the horizontal output transformer (flyback transformer) has its lead wire connected to the anode of the picture tube. Television high-voltage power supplies must furnish from 7,000 to 30,000 volts to operate the picture tube.

Exercise

1. What is the main function of a power supply?
2. What are the three main stages of a power supply?
3. What are the components in the conversion stage?
4. What is the function of the output stage?
5. What stage contains the primary coil of a transformer?
6. What stage contains the transformer secondary?
7. How many diodes does a half-wave rectifier use?
8. How must the half-wave rectifier be biased?
9. When the AC in the primary changes direction and swings positive, how is the diode biased?
10. What is the output of a half-wave rectifier?
11. How does a full-wave rectifier conduct current?
12. What is the diode arrangement for a full-wave rectifier with a negative output?
13. What does the center-tapped transformer do?
14. How can the polarity of a DC power supply be changed?
15. What is the diode arrangement for a bridge rectifier?
16. How many diodes in the bridge rectifier will be conducting current at any particular instant?
17. What is the direction of current flow in the output circuit for each half cycle of conduction?
18. How is a low-voltage supply defined?

G-7

Electron Beam Deflection

Objectives: After completing this assignment, you should be able to—

1. describe the interlace system of television scanning and how it operates;
2. tell how the vertical and horizontal sync pulses are transmitted; and
3. discuss the horizontal deflection circuit.

The Electron Beam Trace and Retrace

The electron beam in a video camera scans the electron image and responds to the point-to-point brightness of the picture. As you learned earlier, the beam begins at the top left corner of the picture and scans from left to right. The standard United States television scanning system is called the **interlace system**. This system uses 525 horizontal scanning lines. The odd lines of the scanning pattern are scanned first, as shown in figure 1. In a single flash, the horizontal-scanning beam covers these odd-numbered lines from top to bottom of the picture. These 262½ odd-numbered lines are called a *field*. The beam then returns to the top to scan the even-numbered lines in another flash. This completes the next field for a total of 525 horizontal scanning lines. This is called a *frame*. This corresponds to one still picture frame on a motion picture film. Thirty of these complete picture frames are transmitted in one second. This is the standard *frame frequency* in the United States for monochrome television systems. One-thirtieth of a second after a particular image has been transmitted, a second one is sent and so on. Of course, the second image is slightly different from the first because of the motion in the scene.

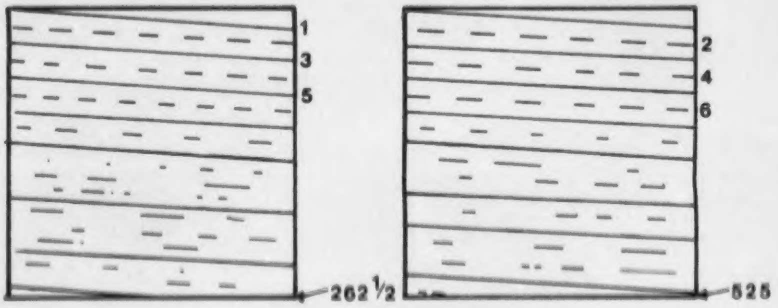

Fig. 1. Interlace scanning system

After the electron beam has scanned one line, it must instantly *fly back* to the left to start scanning the next line—as you would read a book. This flyback time would show a visible retrace line on the picture screen if the beam were not blocked out during this time. When the beam has scanned to the bottom of the picture, it must be returned to the top. During this *vertical flyback* time, the picture must also be black to prevent visible trace lines.

Vertical and Horizontal Sawtooth Voltages

A sawtooth voltage waveform, as shown in figure 2, is produced by special oscillator circuits. These oscillators produce scanning and flyback voltages for the horizontal and vertical beam deflection circuits. The horizon-

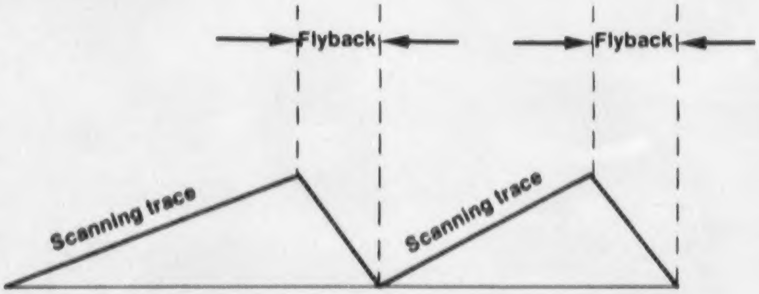

Fig. 2. Sawtooth waveform

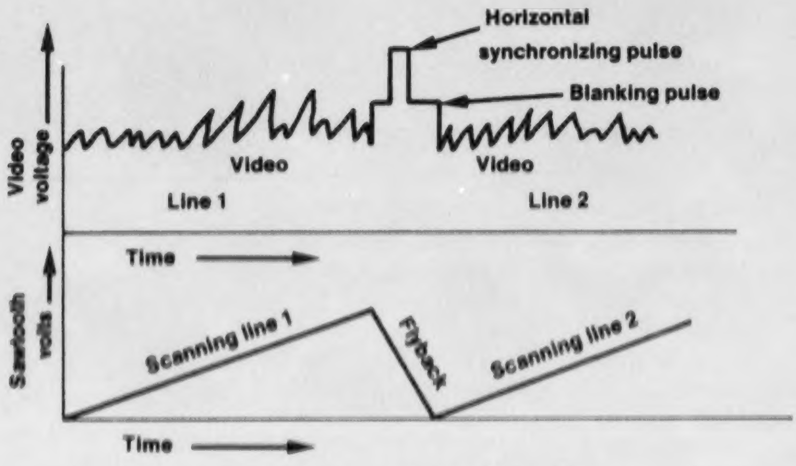
Horizontal synchronizing pulse
Blanking pulse
Video voltage
Video
Video
Line 1
Line 2
Time
Sawtooth volts
Scanning line 1
Flyback
Scanning line 2
Time

Fig. 3. Electron beam scanning

tal and vertical deflection voltages are applied to the horizontal deflection coil and the vertical deflection coil, respectively. These coils are in the deflection yoke. You learned about this in Assignment G-5.

Figure 3 illustrates electron beam scanning for two lines. The sawtooth voltage rise and decline is compared to the envelope of the composite video voltage shown above it. The video portion is scanned for one line, and at the end of the line a blanking pulse along with the horizontal synchronizing pulse is transmitted. Notice that directly below this blanking time, or blackout time, the flyback voltage drops from its peak to zero voltage. At the end of the blanking pulse, the electron beam flashes on again. As the second line of video information is scanned, the sawtooth voltage again climbs until it reaches its peak at the end of line two. Another blanking and horizontal synchronizing pulse is transmitted, and the entire process is repeated. It is repeated line by line until the entire screen has been scanned. The beam then returns to the upper left-hand corner to begin to scan another frame. The beam must be blanked out, just as it was during the horizontal scanning, to prevent its retrace from appearing in the picture. For this purpose a long vertical pulse is transmitted. This pulse must be about 15 times longer than the time interval for horizontal scanning. The vertical sync pulse, like the horizontal sync pulse, is about 25 percent greater in amplitude

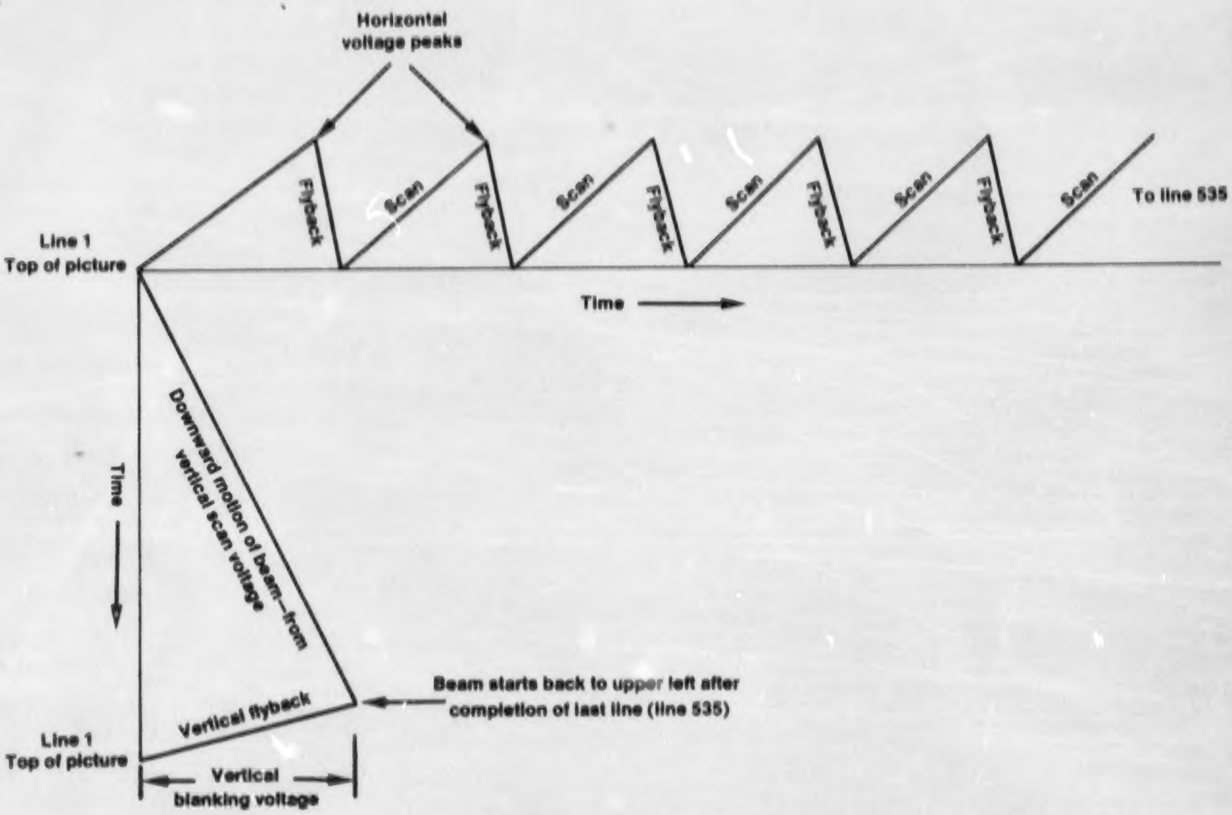
Horizontal voltage peaks
Flyback
Scan
Flyback
Scan
Flyback
Scan
Flyback
Scan
Flyback
Scan
To line 535
Line 1
Top of picture
Time
Time
Downward motion of beam—from vertical scan voltage
Vertical flyback
Beam starts back to upper left after completion of last line (line 535)
Line 1
Top of picture
Vertical blanking voltage

Fig. 4. Vertical and horizontal scanning

than the blanking pulse. The greater amplitudes of the pulses allow them to be separated by the synchronization separator circuits that you will learn about in Assignment G-8.

A simplified version of how the vertical and horizontal sawtooth voltages operate to provide a proper *raster* is shown in figure 4. The total scanning pattern of 525 lines causes the TV screen to appear constantly illuminated to the eye even when the television is tuned to an empty channel and there is no picture. This is called the television raster. Figure 4 shows how simultaneous vertical and horizontal sequential scanning can produce a complete television raster.

To prevent the horizontal sawtooth oscillators of the receiver from falling out of step with those at the transmitter, the horizontal sync pulses are not cut off during the vertical retrace time. The design of the sync separating circuits prevents them from interfering with each other. Since the United States standard horizontal scanning frequency is 15,750 Hz and the vertical scanning rate is only 60 Hz, the frequencies can easily be separated by special bandpass filters in the sync separator circuit.

The Horizontal Beam Deflection Circuit

The horizontal deflection circuit is called a *flyback system*. Figure 5 shows an arrangement of components in a horizontal deflection circuit. As you can see, the flyback transformer (horizontal output transformer) T-1 is the main component of this circuit.

The electromagnetic energy from the flyback transformer and the horizontal deflection coils are used to accomplish the horizontal beam scanning and retrace functions. When the horizontal output transistor Q$_1$ conducts, current is delivered to the horizontal deflection coils in the yoke. Earlier you learned that the magnetic fields, caused by this current moving through the coils, move the beam to scan the screen in the proper manner.

Several bias voltages are provided by the flyback transformer. Output voltages are delivered to operate the focus grid of the picture tube, and provide a positive DC high voltage to the

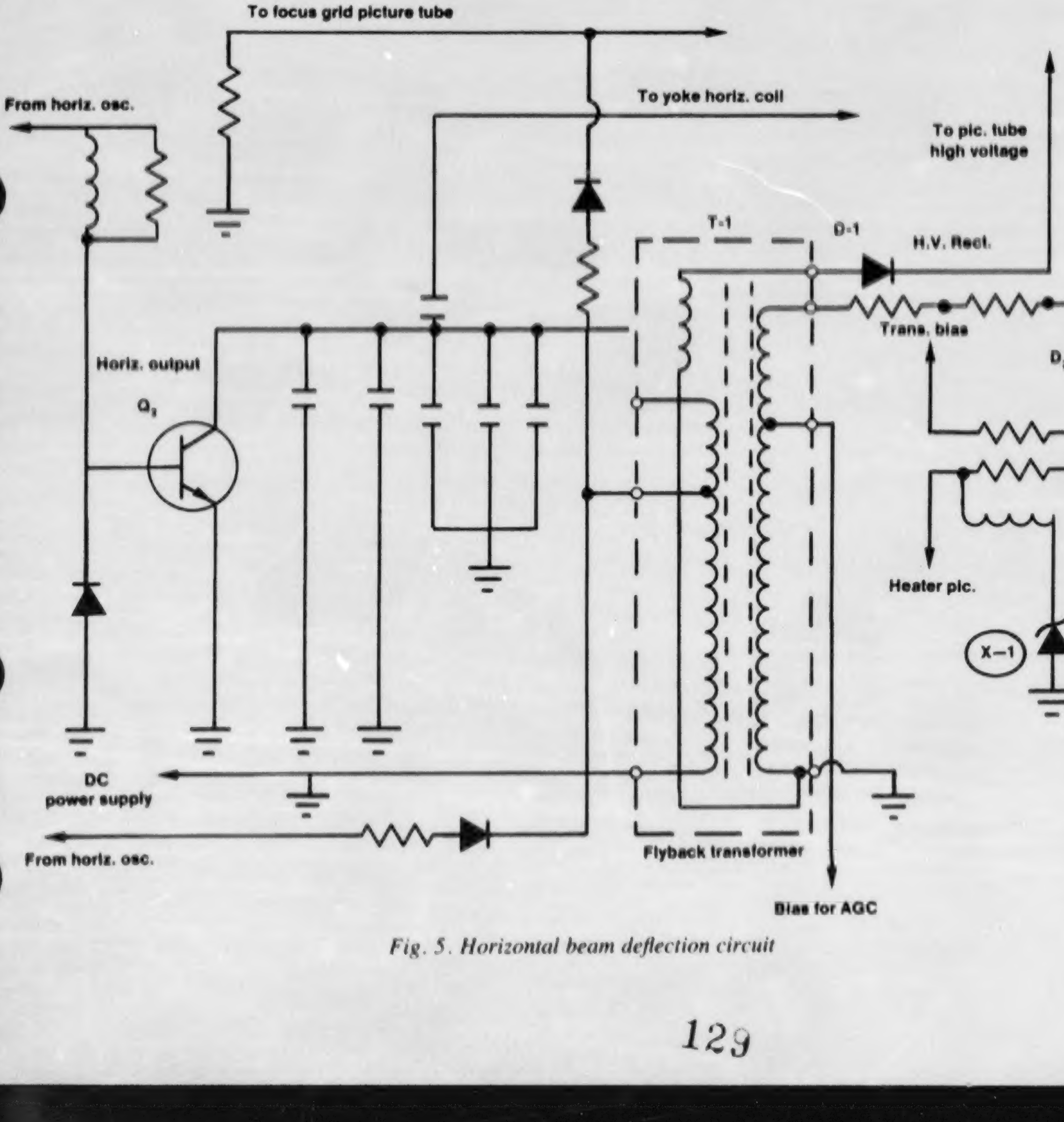

Fig. 5. Horizontal beam deflection circuit

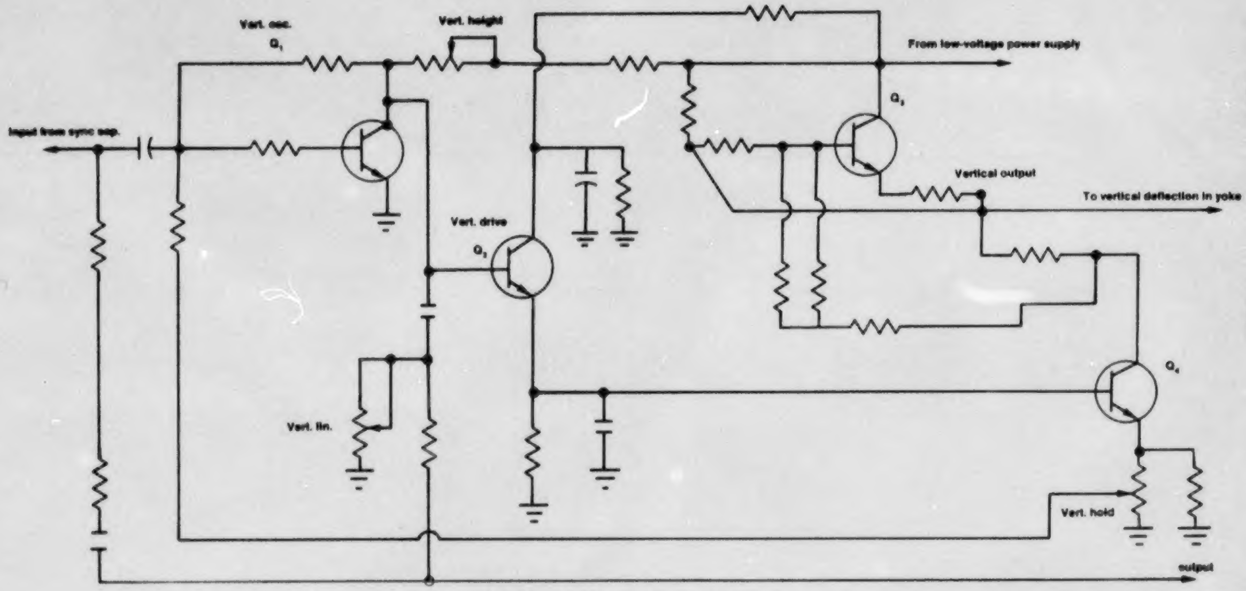

Fig. 6. Vertical beam deflection circuit

anode of the picture tube. This high voltage is fed from a special winding shown at the top of T-1 through a diode rectifier (D-1). Diode D_2 is called a *damper diode*. Its purpose is to prevent oscillation in the horizontal deflection circuit that would distort the picture. Another important component shown in the flyback circuit is the *zener diode* X-1. This is a special type of diode that performs the valuable function of voltage regulation. Several transistor bias voltages are provided from the flyback transformer as well as a special lead to feed the heater element of the cathode-ray tube.

The Vertical Beam Deflection Circuit

A simplified version of a vertical deflection circuit is shown in figure 6. The vertical synchronization pulses are fed from the sync separator circuit to the base of the vertical oscillator transistor Q_1. The vertical deflection sawtooth voltage is produced in the oscillator and fed to the base of the vertical drive transistor Q_2 by direct coupling. Sufficient power amplification is provided to drive the vertical deflection yoke from the vertical output transistors Q_3 and Q_4. The circuit also provides the necessary amplification to perform the operation of vertical retrace blanking. The other functions of the vertical deflection circuit are to provide adjustable controls for vertical linearity, vertical height, and vertical hold. These will be covered in Assignment G-9 on television controls and adjustments.

Exercise

1. How does the beam in a video camera scan the electron image?
2. What is the interlace system?
3. How is a field scanned?
4. What is a frame?
5. What is the standard frame frequency for U.S. monochrome TV systems?
6. What happens after the electron beam has scanned one line?
7. When are the blanking pulse and horizontal sync pulse transmitted?
8. When does the sawtooth voltage reach its peak as the second line of video information is scanned?
9. How long is the transmitted vertical pulse?
10. How do the amplitudes of the sync pulses compare to the blanking pulse?
11. How is a complete raster produced?
12. How are the horizontal and vertical scanning frequencies separated?
13. What is a flyback system?
14. What is the main component of a horizontal deflection circuit?
15. How is horizontal beam scanning and retrace accomplished?
16. What is the function of the zener diode in the flyback circuit?
17. What kind of coupling is used between the vertical oscillator and vertical drive transistors?

G-8

Synchronization and the Sync Separator

Objectives: After completing this assignment, you should be able to—

1. explain why DC restoration is necessary;
2. explain how vestigial sideband transmission is used in the United States;
3. explain negative transmission; and
4. explain how filter networks are used in the sync separator.

You have just learned how sawtooth scanning waveforms produce the picture tube raster. Synchronization pulses are also transmitted in the composite signal to ensure that these sawtooth scanning waveforms are in step with the sawtooth scanning action taking place in the transmitter's camera tube. The synchronization separator and deflection oscillator circuits are very closely associated and are basic to the operation of all types of television receivers.

The DC Restoration Function of the Sync Separator

When the direct current component of the composite video signal has passed through coupling capacitors, it is blocked and therefore is lost. This usually has happened when the composite signal passes through the video detector. The DC component is a vital ingredient to the television picture since it relates to the average brightness of the scene. For this reason, DC restoration is one of the necessary functions of the sync separator circuit.

The sync separator circuit is designed so that from a sampling of the amplitudes of the AC component it can reproduce or restore the DC component in the same proportions as it was before. Diodes are usually used to accomplish this by a process called *diode clamping*.

Vestigial Sideband and Negative Transmission of Sync Pulses

You learned earlier in Section F, "Basic Radio," that both the upper and lower sidebands contain the same intelligence. The same is true for the transmission of video information. If one of the sidebands were removed, the picture information would still be carried to the receiver by the other sideband. The Federal Communications Commission (FCC) requires that the upper sideband be transmitted while part of the lower sideband is suppressed. This is called **vestigial sideband transmission**. It has been adopted because it saves valuable channel space.

The FCC also requires that **negative transmission** be used in the United States. This means that when the picture is very white, the video amplitude is quite low. As the video amplitude becomes higher, the TV picture becomes darker. The maximum black level is fixed at 75 percent of the carrier peak voltage (see fig. 1). This is called the *pedestal level*. As transmitter power decreases, the picture becomes whiter. To conform to FCC regulations, the white level may not exceed 12.5 percent of the maximum

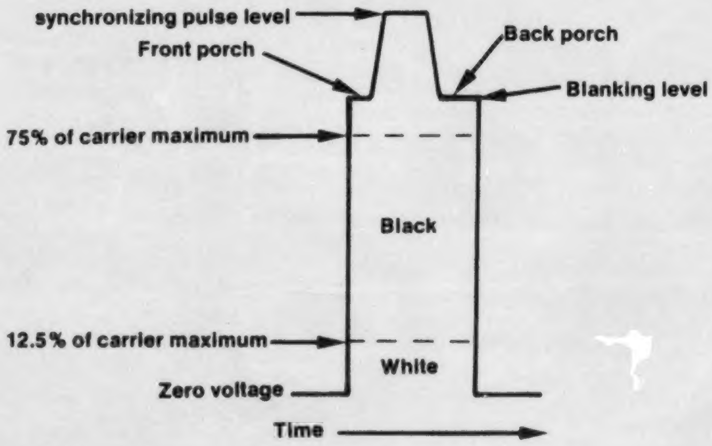

Fig. 1. Blanking and horizontal synchronizing pulse for negative transmission

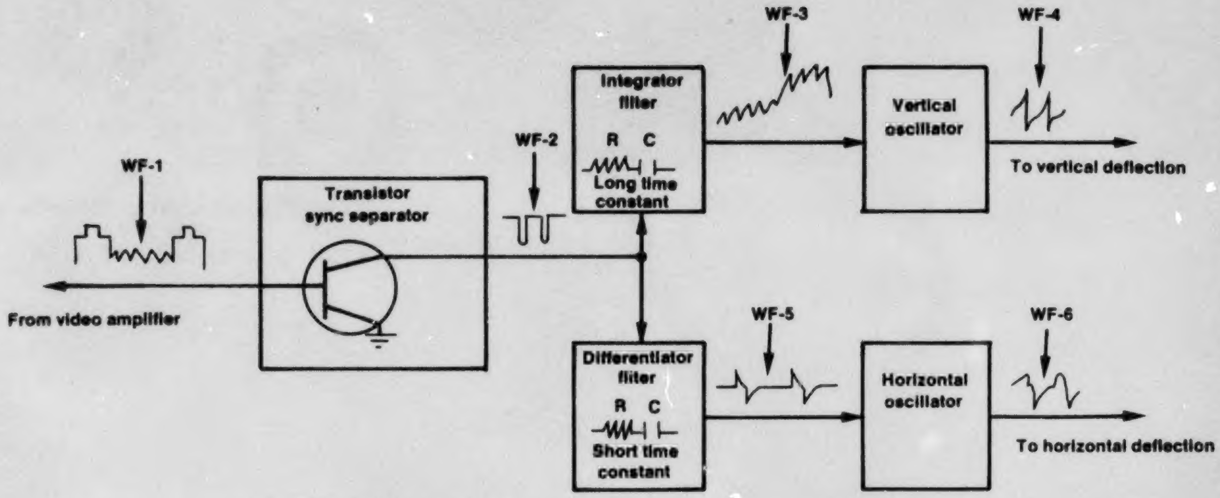

Fig. 2. Relationship of sync separation stage to deflection oscillators

carrier amplitude. The predominantly used intercarrier television transmission system maintains the white level at no less than 10 percent of carrier maximum. From the point of zero voltage, the voltage climbs to the *front porch* of the blanking level. It climbs on to the synchronizing pulse level, and then drops down to the *back porch* portion of the blanking level. It then declines through the levels of black to white and again to zero voltage.

Synchronization signals are transmitted with picture information to provide the correct timing for the vertical and horizontal sweep scanning movement. A horizontal sync pulse is transmitted for each horizontal scanning line. This keeps the horizontal scanning of the transmitter and receiver synchronized. The transmitter and receiver vertical scanning is also kept in step by having a vertical sync pulse transmitted for each scanning field. Synchronization pulses are transmitted during the retrace time, or blanking time (when the screen is blanked out). To accomplish this, a blanking pulse must be transmitted.

The TV Receiver Sync Separator

The sync pulses must be separated from the composite video signal before they can be used to control the timing of the beam deflection oscillators. The **sync separator circuit** is designed especially to do this job as well as several other functions. The function of DC restoration has already been mentioned.

The sync separator circuit *clips off* the video signals below the blanking level. The composite video signal waveform (WF-1) is fed to the base of the transistor sync separator, as shown in figure 2. The sync pulse (after clipping and amplification) waveform WF-2 is shown at the collector output before it is filtered. Actually, only the horizontal sync pulse is shown, but the vertical sync pulse is also present. The vertical sync pulse has the same amplitude but differs in width, or the length of time for each pulse.

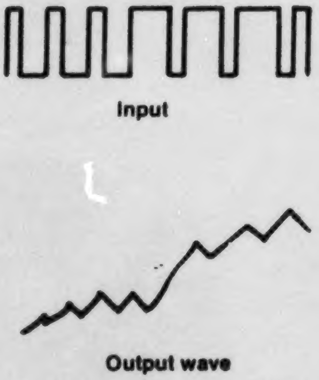

Fig. 3. Conversion of vertical sync pulses to output wave

Separation of Vertical and Horizontal Sync Pulses

The transistor output feeds into two different filter networks, called an *integrator* and a *differentiator*. An integrator is a low bandpass filter circuit designed to block the higher-frequency horizontal pulses but allow the lower-frequency (60 Hz) vertical sync pulses to pass. The differentiator does the exact opposite. It has a high bandpass filter that blocks the vertical sync pulses but allows the horizontal sync pulses to pass. To understand these circuits better, you should review Assignment C-5 regarding the R C time constant.

Integrating Circuit

A simple R C combination becomes an integrating circuit. The charging time of the capacitor is made long compared to the length of time that the input pulses last. The capacitor cannot be completely charged by any single pulse. Each pulse partially charges the capacitor to a low voltage. This charge leaks off through the resistance during the long intervals between pulses. When the vertical sync group of pulses begins to charge the capacitor, the voltage begins to build up more and cannot leak off as easily. The reason for this is that the spacing (or serrations) between the pulses is less than their duration. This is illustrated in figure 3. The first three pulses shown at the input are called equalizing pulses. As can be seen, the next three vertical sync pulses are of long enough duration to cause the voltage buildup in the output waveform. This explains how the waveform WF-3 in figure 2 from the integrator output has been formed. WF-3 is also the input waveform for the vertical oscillator. It is now a large enough voltage to trigger the oscillator. The vertical oscillator circuit was covered previously. The sawtooth output is amplified and fed to the vertical deflection yoke.

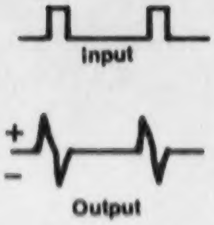

Fig. 4. Conversion of horizontal sync pulses to output wave

Differentiating Circuit

An input pulse delivered to the R C combination in the differentiator circuit charges the capacitor through the resistor. The capacitor charging time is made short compared to the length of the applied pulses. This causes the circuit to only respond to changes in pulse waveform. The horizontal sync pulse causes the capacitor to charge quickly to peak voltage at the start of the pulse. With input voltage removed, the capacitor will discharge through the resistor in the opposite direction. This causes a negative discharge pulse to appear in the output at the trailing edge of the input pulse. The negative output pulses will be clipped off in the circuit. The positive pulses only will be used to synchronize the horizontal oscillator.

The output positive pulses from the differentiator (see fig. 4) are strong enough to trigger the horizontal oscillator (see fig. 5) to generate the output waveform WF-6. This signal will receive amplification in the horizontal output stage so that it can supply the sawtooth voltage to operate the horizontal deflection yoke, as you learned earlier.

Exercise

1. How are sawtooth waves in a TV receiver kept in step with those at the transmitter?

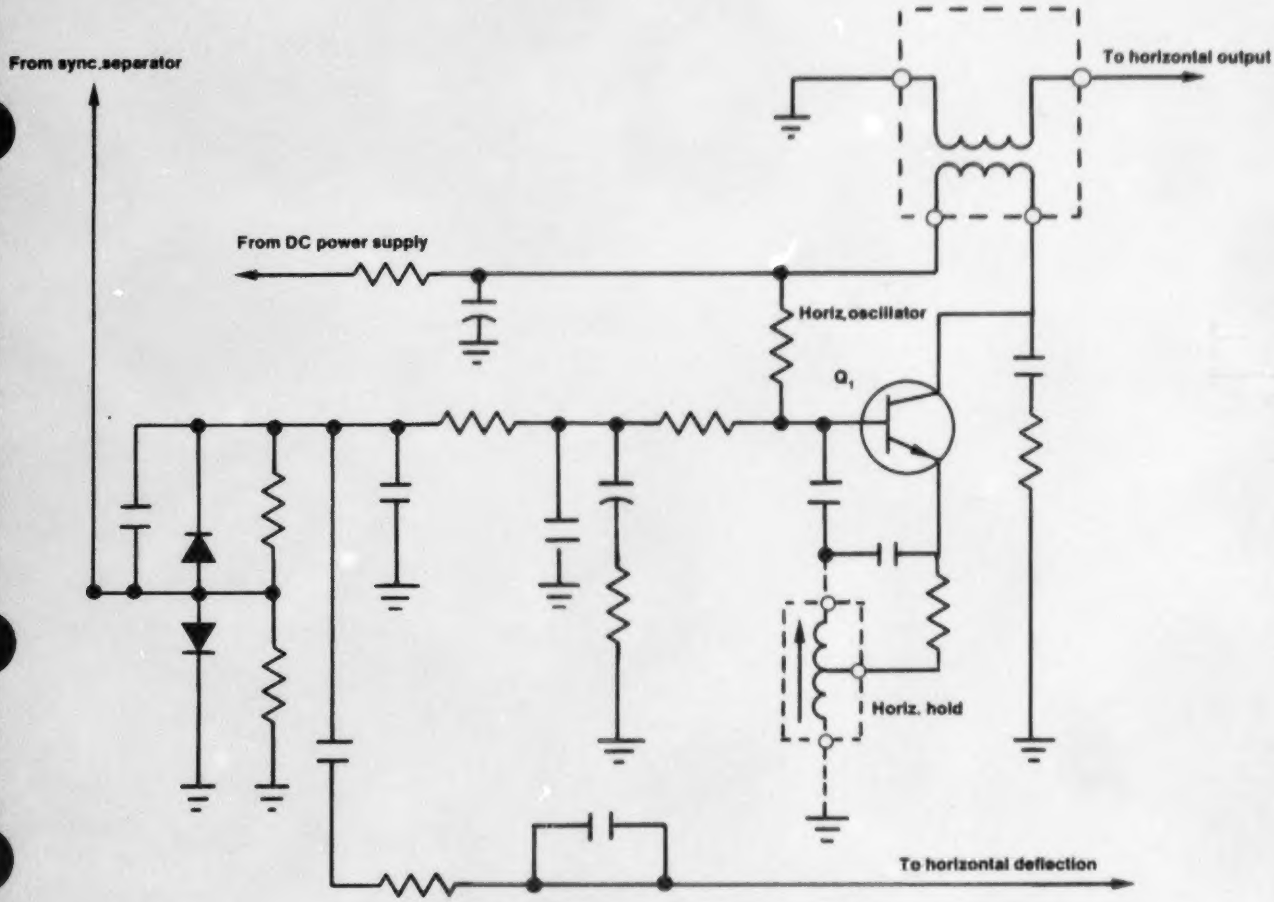

Fig. 5. Horizontal oscillator

2. Why is the DC component important to the TV picture?
3. What TV circuit is responsible for DC restoration?
4. How can the sync separator restore the DC components?
5. What is vestigial sideband transmission?
6. What is the maximum black level fixed at?
7. What is the range for the white level?
8. How are horizontal sync pulses transmitted?
9. How is the vertical scanning kept in step?
10. Why must sync pulses be separated from the composite video signal?
11. What is the function of the integrator?
12. What is the function of the differentiator?
13. What does a simple R C combination (long charge) become?
14. How is the capacitor charging time in the integrator different from that in the differentiator?
15. How is the horizontal oscillator synchronized?

G-9

Television Controls and Adjustments

Objectives: After completing this assignment, you should be able to—

1. explain the purpose of the picture channel controls;
2. explain the purpose of picture scanning controls; and
3. explain how a test pattern generator is used.

There are four general categories of controls in a television receiver. These are the picture channel, sound channel, scanning, and general controls.

Picture Channel Controls

The picture channel controls are the *brightness*, *contrast*, and *focus controls*. They are usually located at the front or side of the set, in one of the general areas shown in figure 1.

The **brightness control** regulates the average brightness of the picture tube screen. It was designed to prevent the beam from being visible when it returns to start a new scanning sweep. It also regulates the bias voltage between the grid and cathode of the picture tube. The *center range* for this control, as well as for the other controls, can be considered as about the ideal point of adjustment for a television set that is operating properly. The control can be advanced or retarded from this point to increase or decrease the brightness of the picture.

The **contrast control** can be adjusted to change the black-and-white contrast between the various parts of the picture. The gain of the video IF amplifier is varied by adjusting this control. To increase the contrast between light and dark parts of the picture, the control should be advanced. This also causes an increase in the general illumination of the screen. In extremely bright rooms, an increase in contrast may often be necessary.

The **focus control** is the adjustment used to regulate the small spot (the pip) that is made bright by the electron beam striking the screen. It is usually set for the smallest spot possible to give the finest picture detail.

Tuning and Sound Channel Controls

The sound channel controls are the same as for ordinary FM radio re-

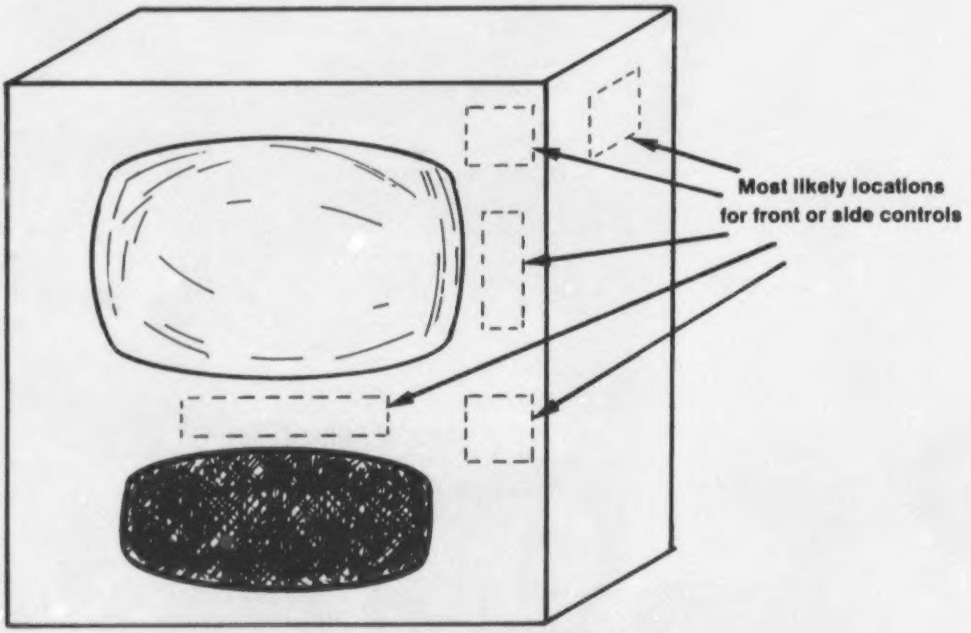

Fig. 1. Locations of picture channel controls

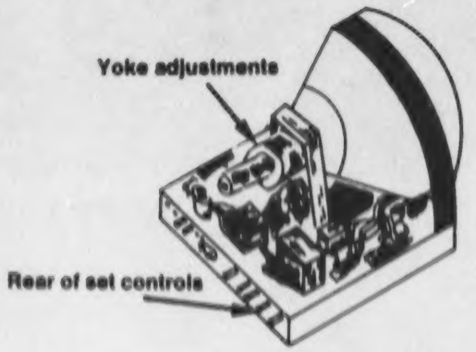

Fig. 2. Chassis location of scanning controls

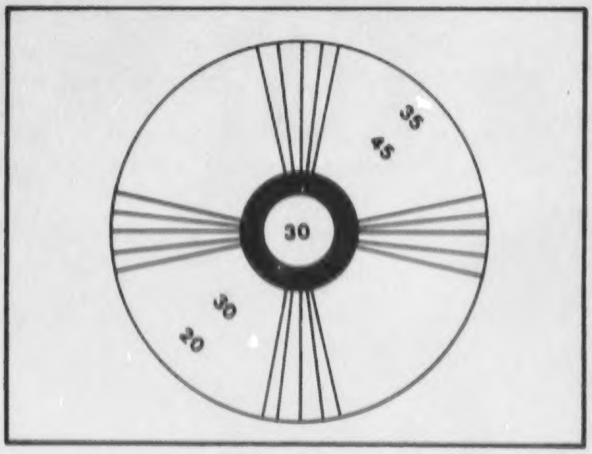

Fig. 3. Simplified version of test pattern

ceivers. Of course, the sound and tuning controls must always be located at the front or side of the set with the brightness and contrast controls. This is for the convenience of the viewer, who will be operating them. Usually in about the same location is placed an on-off switch or button. It is often made as an integral part of the sound volume control, along with a small light that is lit when the set is on.

Picture Scanning Controls

Most of the scanning controls are placed on the TV chassis at the rear of the set (see fig. 2). The reason for this is that they have been designed more for the use of the service technician than for the viewer. Regardless of the location, they are always labeled so they can be identified. It is often in abbreviated form, such as Vert-Lin for the vertical linearity control.

The *vertical linearity* control adjusts the shape of the vertical scanning wave. The *horizontal linearity* control regulates the shape of the horizontal scanning wave. The *horizontal drive* control adjusts the ratio of pulse amplitude to the linear portion of the horizontal scanning wave. This is not included on late-model sets. The *horizontal and vertical hold* controls allow for the adjustment of the frequencies of the two scanning systems for lock-in (synchronism) with the transmitted sync pulse. The *width* control adjusts the horizontal size of the picture, and the *height* control adjusts the vertical size of the picture.

General Controls

There are so many different designs and controls for television sets that it would be impossible to cover all the arrangements and types of hardware used for general controls. Some television sets provide for adjustment of the picture tube yoke and centering of the picture tube. The manufacturer's data sheets for the particular year and model number of television should be consulted for such adjustments.

Test Pattern Generator

Many television receiver adjustments and troubleshooting procedures make use of a *test pattern generator*. The service technician can properly adjust receiver controls for the best picture by using a test pattern (see fig. 3). If circles appear oblong, numbers are blurred, or lines are distorted, these symptoms may be related to problem areas in the television set.

Exercise

1. What is the function of the brightness control?
2. What range should be considered the place to start adjustments of a control?
3. What is the function of the contrast control?
4. What does the focus control regulate?
5. How is the focus control usually set?
6. What does the vertical linearity adjust?
7. What does the horizontal linearity adjust?
8. What does the horizontal drive adjust?
9. What is the function of the horizontal and vertical hold controls?
10. What does the width control adjust?
11. What does the height control adjust?
12. What is a test pattern generator used for?

Objectives: After completing this assignment, you should be able to—

1. explain the system of color mixing used for color television;
2. explain how the chrominance information is transmitted; and
3. explain how the phosphors on the color picture tube screen are excited to produce the desired colors.

G-10

Color Television

Imagine that you have placed two painted objects of different colors close together on some sort of rotating device. This will allow them to be rapidly spun around, like wooden horses on a merry-go-round. If this is done, the colors will blend together and form a third color. The smaller the objects to the human eye, the harder it is to identify their color.

The Additive Process of Color Mixing

A system of color mixing has been developed for color television. It is called the *additive process*. Three primary colors are used for this mixing. They are *red*, *green*, and *blue*. Any color used in color television can be created by the matching of various combinations of these three colors.

Now imagine three separate flashlights shining their light beams on a screen. The colors of the beams are red, blue, and green. The light beams overlap, as shown in figure 1. In the area (designated Y) where red and green go together or mix, the new color is yellow. In the same manner, red and blue mix to form magenta (M), and blue and green mix to form cyan (C). When all three of the primary colors of red, blue, and green are mixed, the new color (designated W) formed is a white light.

Black is not considered to be a color. Black is actually the absence of light. The redness, blueness, or yellowness of light is called the *hue*. The hue refers to a particular wavelength or range of wavelengths that includes that light color.

Luminance and Chrominance

Luminance is the term used to describe the brightness of light. If the luminance is changed, the appearance of a color remains somewhat constant over a wide range of luminance. Only luminance information needs to be transmitted for the fine detail in a picture. The luminance television signal contains a high-frequency component to carry this picture information. The symbol for the luminance signal is the letter Y. The two parts of the *color video voltage* are the *luminance* voltage and the *chrominance* (color) voltage.

Essentially, color television sets operate in the same manner as monochrome sets. In color sets, the color signal is still within the same 6 MHz channel width. The same number of scanning lines (525) are scanned per frame. The video band width is also 4.25 MHz. What is added is a *chrominance signal*.

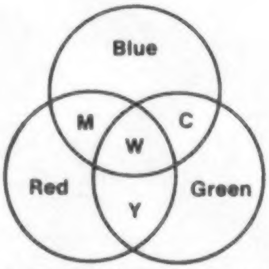

Fig. 1. Basic light colors created by the additive primaries

The Basic Color Television Sections

There are certain sections in the color receiver (shown in figure 2 by the cross-hatched lines) that deal especially with the chrominance. The composite video signal enters the input circuit of the RF amplifier, is converted, and its output fed to the IF amplifier. Another conversion takes place in the IF amplifier, and the output is fed to the video detector and amplifier section. Up to this point (see fig. 2), the input, conversion, and output stages are the same as for a monochrome television system. It is at the outputs of the video detector and amplifier section that the special color circuits are located.

Required Functions of the Color Receiver

In the design of all color receivers, the color circuits must be made *compatible* with the monochrome circuits. This means that a monochrome signal can be picked up by a color receiver and reproduced as a monochrome picture. Also, a monochrome receiver must be able to pick up a color-transmitted signal and reproduce it as a monochrome picture. Besides these two requirements, color receivers must reproduce color transmissions in color.

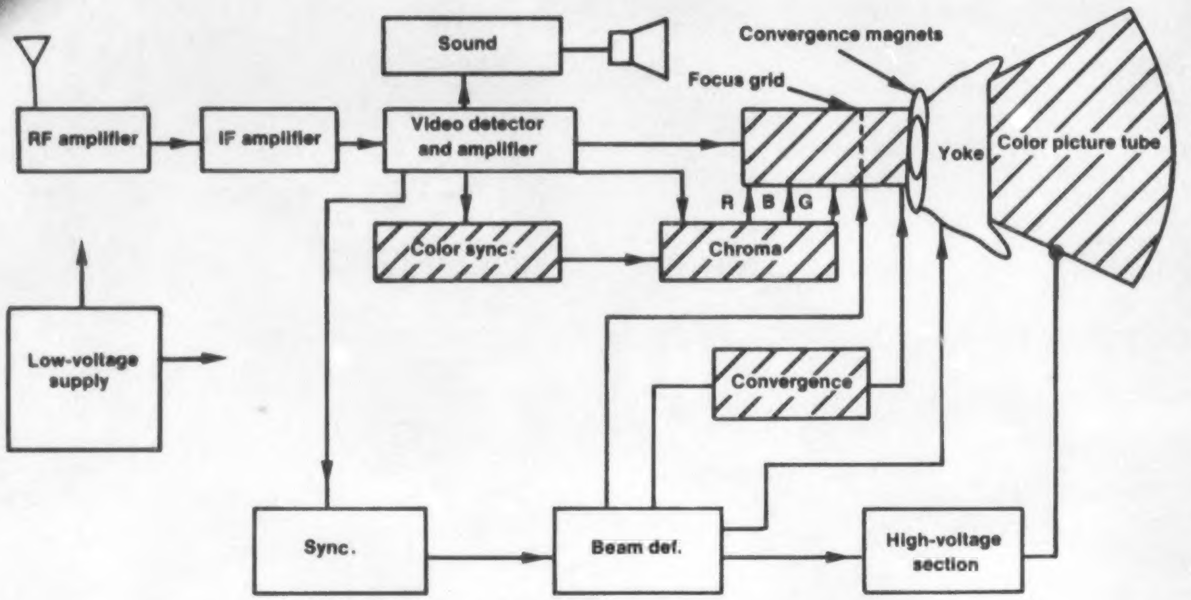
Sound
Convergence magnets
Focus grid
RF amplifier
IF amplifier
Video detector and amplifier
Yoke
Color picture tube
R
B
G
Color sync.
Chroma
Low-voltage supply
Convergence
Sync.
Beam def.
High-voltage section

Fig. 2. Block diagram of a color television set

The three primary colors of red, green, and blue are not transmitted as separate color information. The color transmission is actually done through a *luminance signal* and a *chrominance signal*.

The information needed by monochrome sets is carried by the luminance signal. This signal also regulates the brightness of various spots in the picture of a color receiver. The necessary information from the chrominance signal to reproduce the color picture is removed by the color receiver and used in the color sections shown in figure 2.

When the TV signal is transmitted, a carrier for picture modulation and another one for audio modulation are necessary. There must also be room for the chrominance modulation in the television channel. A *subcarrier* must be used to fit in the chrominance modulation. The television channel allocations are shown in figure 3. Negative transmission is used just as in the monochrome system. The transmission of the chrominance information within the same monochrome 6 MHz band width is called *frequency interlacing*.

The chrominance subcarrier is called a subcarrier because it is really a modulated-modulation component of the

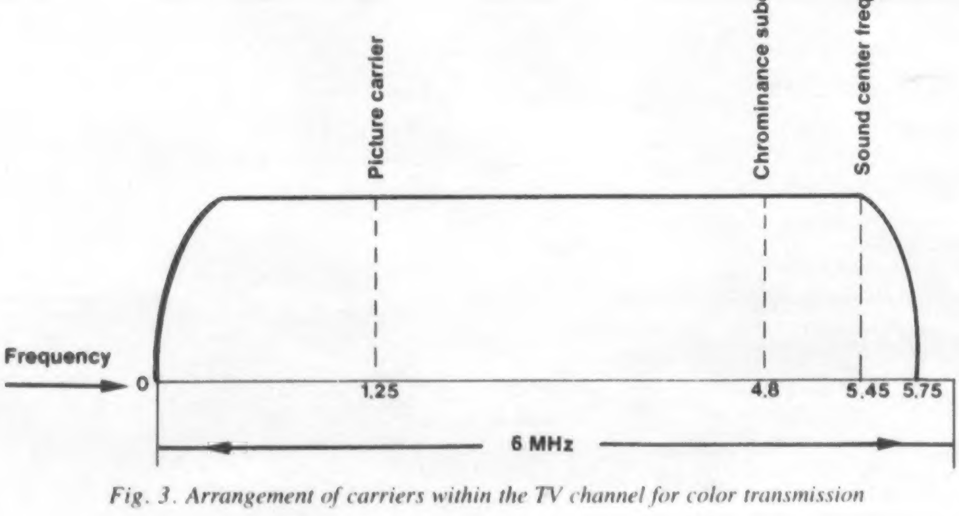

Fig. 3. Arrangement of carriers within the TV channel for color transmission

broadcast station's composite signal. By using a subcarrier, the color information in the video band is located at a specific distance in frequency from the picture carrier. The result is that there is less interference caused by the chrominance to disrupt monochrome pictures. It also permits the separating of the luminance information by using demodulating circuits. Remember that the chrominance subcarrier is modulated with the chrominance signals. Its sidebands are used to modulate the picture carrier.

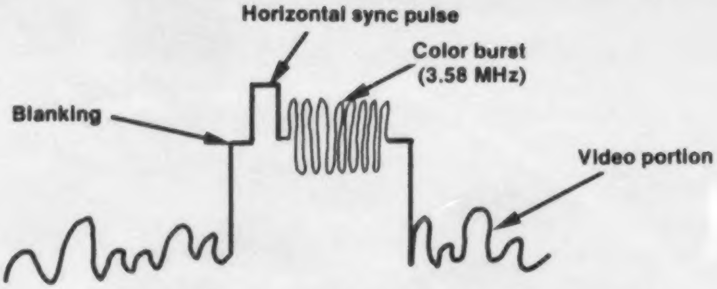

Fig. 4. Rectified composite video signal input to burst amplifier

The Matrix Circuit

A number of signals must be combined to produce a specified output signal as one of the requirements of a color system. The circuit that accomplishes this is called a *matrix*. A black-and-white camera is not needed in a color system because the Y signal (luminance) from the color cameras can carry all this information. Color adding of 59 percent of the green signal, 30 percent of the red signal, and 11 percent of the blue signal results in the Y signal. These percentage outputs are produced by simple voltage divider resistors.

It is not necessary to use a color camera to transmit each of the primary colors. Only two cameras need to be used for transmission in a color system. The red, green, and blue signals are changed into *color difference signals*. These signals are called *R-Y* for red minus Y and *B-Y* for blue minus Y. The three color signals have been reduced to two signals by the use of the matrix. In the color receiver, matrix circuits are able to reproduce the green color even though it was not transmitted. This is done by extracting a G-Y signal from the B-Y and R-Y signals. By adding the Y signal to each of the color difference signals, the original red, blue, and green signal outputs are fed to the color electron guns in the neck of the picture tube.

Color Sync

The output from the video detector and amplifier that is fed to the color sync section (see fig. 2) contains the rectified *composite video signal*. Figure 4 shows the components of this waveform. Contained on the back porch is the *color burst signal*. This synchronizing interval of about 2.2 microseconds is referred to as the *color burst*. This color burst is actually a small sample of the transmitter's 3.58 MHz color subcarrier. The subcarrier is suppressed at the transmitter, so it must be reinserted in the color receiver by the receiver's 3.58 MHz local oscillator. The sync color burst happens when the picture is blanked out.

A *burst amplifier* stage in the color sync section separates the burst signal from the composite video signal. The output from the 3.58 MHz local oscillator is fed to two color demodulator stages, usually called the X demodulator and the Z demodulator, to begin the matrix process that has already been mentioned.

The Chroma Section

In the chroma section, a special *bandpass amplifier* receives color information as amplitude- and phase-modulated signals from the video section. The color is separated from the video and amplified. It is then applied to the phase demodulators.

The Convergence Section

Special circuits are needed to control the precise movements of the three color beams in the picture tube of the color receiver. Actually, three separate (identical) pictures are reproduced on the screen with each of the three guns driven by the receiver circuits. The output from the convergence section is fed to special convergence magnets. The fields from these magnets (attached outside the neck of the tube) cause the three color beams to converge together and strike the screen at specified points.

The Color Picture Tube

Three electron guns are used in the color picture tube—one for each of the primary colors red, green, and blue. There are also three different phosphors used on the screen of the receiver. They are red, green, and blue to correspond to the red, green, and blue electron beams emitted from the electron gun. The electrons excite each of the three phosphors to reproduce the transmitted color scene. Control grids in the guns regulate the intensity of the beams. They also provide vertical and horizontal sweep, as well as accelerating voltages, that shape the beams and control the speed of the electrons.

One type of color screen has the phosphors arranged in groups of three dots (red, blue, and green) called *triads* (see fig. 5). These triads are placed very close together, but they do not overlap. Regardless of the type of electron gun assembly used in a color picture tube, it provides a red beam to excite the red dots, a blue beam to excite the blue dots, and a green beam to excite the green dots. On some color receivers, the phosphor screen contains about 333,000 triads, for a total of 999,000 color dots.

The color picture tube also contains a thin shield with openings or apertures designed to allow the color beams to pass through it and strike only the color triads. It is called a *shadow mask*. The shadow mask is placed

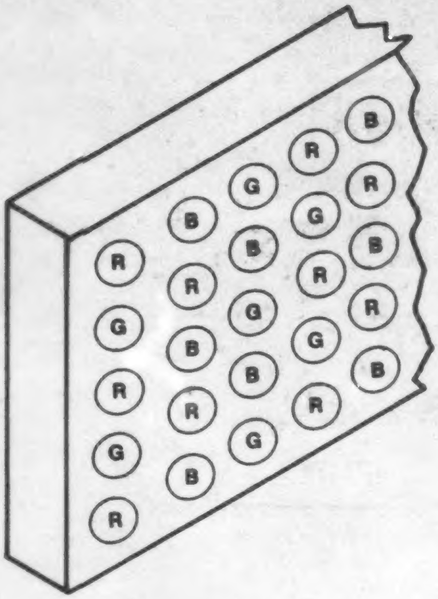

Fig. 5. Phosphor triad screen

close to the phosphor screen between the screen and the electron gun assembly. A simplified version of the *circular aperture* type of shadow mask arrangement is shown in figure 6. Several other types of shadow masks are used today. They may use different types of apertures, such as the slot, the rectangular slot, and the continuous slit.

There are also other methods used to cover the screen with phosphors. One method coats the screen with blue, red, and green phosphor *stripes* instead of color dots. New developments in the field of electronics will bring about many changes in the design of radio and television sets in the future.

Exercise

1. What is the system of color mixing for color television called?
2. What are the primary colors for this mixing?
3. Which of the primary colors are mixed to obtain yellow?
4. What is the color *hue*?
5. What is luminance?
6. What happens when the luminance is changed?
7. How is the picture information transmitted for color television?
8. What are the parts of the color video voltage?
9. What is added to a color transmission that was not present in monochrome transmission?
10. What basic sections must be added to a color receiver in addition to the monochrome sections?
11. Why can a monochrome signal be picked up by a color receiver and reproduced as a monochrome picture?
12. Which signals are transmitted in color transmission?
13. What information is carried by the luminance signal?
14. What must be done to fit the chrominance modulation into the television channel?
15. What is the desired result of using a subcarrier for chrominance?
16. How can a number of signals in a color system be combined to produce a specified output signal?
17. Why is a black-and-white camera not needed for transmission in a color system?
18. How are the color percentage outputs of the Y signal produced?
19. What new signals are produced when red, green, and blue signals are changed into color difference signals?
20. Why doesn't the sync color burst disrupt the receiver's picture?
21. What circuit functions are performed in the chroma section?
22. What circuits control the precise movements of the three color beams?
23. What color beams are produced by the electron gun assembly?
24. What regulates the intensity of the color beams?
25. What is the color dot grouping called for the circular aperture type of shadow mask tube?
26. Besides the color dots, what is another method of covering the screen with phosphors?

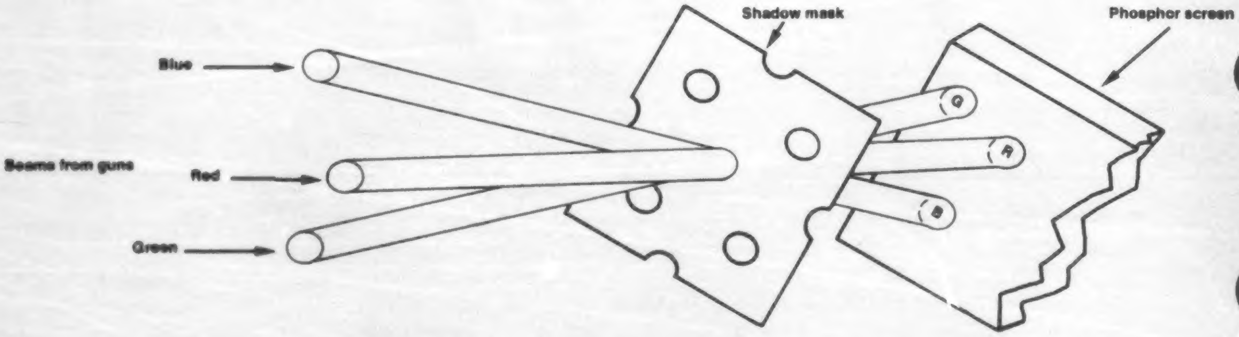

Fig. 6. Convergence of color beams through shadow mask